## *5th International Conference of*

# Forest Engineering and Technologies

# FETEC 2024

***"Forest Operation Technologies and Systems for Small-Scale Forestry Applications"***

# PROCEEDINGS

**16-18 September 2024**

**Ljubljana, Slovenia**

**University of Ljubljana**
**Biotechnical Faculty, Ljubljana, Slovenia**

E-mail: fetec2024@bf.uni-lj.si
https://www.ormantransportu.org/fetec2024

UNIVERSITY OF LJUBLJANA | BF Biotechnical Faculty

FETEC

IUFRO

TAJFUN

# COMMITTEES

## Organizational Committee

**Assoc.Prof.Dr. Matevž Mihelič (Chair)**
University of Ljubljana, Biotechnical Faculty, Slovenia

**Prof.Dr. H.Hulusi Acar (Co-Chair)**
FETEC, Istanbul Yeni Yüzyıl University, Istanbul, Türkiye

**Prof.Dr. Abdullah E. Akay**
IUFRO Division 3.01, Bursa Technical University, Bursa, Türkiye

**Assoc.Prof.Dr. Raffaele Spinelli**
IBE-CNR, Italy

**Prof.Dr. Janez Krč**
University of Ljubljana, Biotechnical Faculty, Slovenia

**Mateja Intihar**
University of Ljubljana, Biotechnical Faculty, Slovenia

**Luka Pajek**
University of Ljubljana, Biotechnical Faculty Ljubljana, Slovenia

## Conference Sponsor

**Tajfun LLC., Planina pri Sevnici, Slovenia**

## Scientific Committee



## Secretarial

Luka Pajek, UL, BF, Ljubljana, Slovenia
E-mail: fetec2024@bf.uni-lj.si
Assist.Prof.Dr. İnanç Taş, BTU, Bursa, Türkiye
E-mail: inanc.tas@btu.edu.tr

# INTRODUCTION

Forestry plays a crucial role in the ecosystem, maintaining biodiversity, providing habitats, regulating the water cycle, and serving as a carbon sink to mitigate the effects of climate change. The forest resources should be managed according to principles of sustainable and close to nature forest management in order to meet needs of today's and future's generations. These two approaches aim to maximize the benefits of forests and to minimize environmental damages by using modern techniques and technological tools in forestry activities. Particularly, forest operations producing wood-based forest products should abide to the precision forestry approach. In recent decades, advanced small-scale forest operations, which are used in non-industrial and site-specific forestry, provide alternative methods well suited for use with precision forestry concept. Besides, small-scale forestry significantly contributes to the bio-economy through forest-based businesses, rural communities, and provision of multiple ecosystem services in many regions of the world. Small-scale harvesting machines have low initial cost and relatively low operating cost, while at the same time, their potential environmental impacts can be considerably lower than with use of large-scale machinery.

**5th International Conference of Forest Engineering and Technologies (FETEC 2024):** "*Forest operation technologies and systems for small-scale forestry applications*" has been organized on **16-18 September 2024** by University of Ljubljana, Biotechnical Faculty in the city of Ljubljana, Slovenia. The conference co-organizers include **FETEC Platform** and **IUFRO Division 3.01**. The sponsor of FETEC2024 is **Tajfun LLC**.

The aim of the conference is to discuss the most recent scientific and professional research related to forest operation technologies and systems for small-scale forestry applications with attendance of internationally renowned researchers, practitioners, and relevant shareholders.

On behalf of the entire organizing committee, I would like to thank all the participants of the conference and express my best wishes to those who contributed during the preparation and organization stages of the conference.

*Assoc.Prof.Dr. Matevž Mihelič*
(Chair)
University of Ljubljana, Biotechnical Faculty
Ljubljana, Slovenia

*Prof.Dr. H.Hulusi Acar*
(Co-Chair)
FETEC, Istanbul Yeni Yüzyıl University
Istanbul, Türkiye

# TABLE OF CONTENTS


Utilizing Decision Trees Models for Machine Selection and Optimal Deployment in Forest Logging Planning. *Mustafa Acar, Selçuk Gümüş* 1

Productivity Calculation of Serial and Parallel Production Systems in Forestry. *Tetsuhiko Yoshimura, Yasushi Suzuki, Noriko Sato* 8

Assessing Forest Fire Susceptibility and Potential Severity in the Wildland-Urban Interface (WUI) with Machine Learning and Google Earth Engine: Case of Izmir Regional Directorate. *Remzi Eker, Kamber Can Alkiş, Ahmet Açıl, Abdurrahim Aydın* 14

Changes in Topsoil Carbon Stock and Some Hydro Physical Soil Properties and Correlations Among Them After Timber Removal in Broadleaf Mixed Forest. *Reyhan Sağlam, Ferhat Gökbulak* 23

How to Save Timber Products from Wildfires by Improving Forest Road Standards? *Abdullah E. Akay, Neşat Erkan, Ebru Bilici, Zennure Uçar, C. Okan Güney* 33

Analysis of Skidder Fuel Consumption by Work Operations During Timber Extraction – Case Study. *Marijan Šušnjar, Zdravko Pandur, Marin Bačić, Hrvoje Kopseak* 38

Assessing the Productivity of Timber Extraction with Lewis Winch. *Neşe Gülci, Abdullah E. Akay, Hasan Yılmaz, M. Emre Yiğit, H. Hulusi Acar, John Sessions* 47

Productivity and Challenges of Combined Forest Management in Japan: A Case Study of *Wasabi* and Timber Production. *Noriko Sato, Minako Iwata Inoue, Tetsuhiko Yoshimura* 51

Silvicultural and Ecological Effects of Machine Use in Forestry. *Sena Yavruoglu, Zafer Yücesan* 58

Detection of Temporal Change in Forest Road Construction Areas with Satellite Imaginary. *Anil Azizoglu, Erhan Caliskan, Gizem Misirlioglu* 64

Determining the Effects of Logging Process on Forest Cover Using Geographic Information Systems and UAV. *Gizem Misirlioglu, Selcuk Gumus, Taha Yasin Hatay* 72

Passing Ability of Medium-Sized Log Trucks in Mountainous Forest Areas in Japan. *Yasushi Suzuki, Tetsuhiko Yoshimura, Hisashi Hasegawa, Kazuhiro Aruga, Masashi Saito, Kai Moriguchi, Hiroaki Shirasawa* 80

Using Drone Captured Images to Estimate Productivity of a Loading Operation. *Ebru Bilici, Halit Büyüksakallı, Gizem Görnaz, Abdullah Emin Akay* 88

Using GIS Techniques to Develop Safe Transportation of Forest Products. *Abdifitah Mohamed Abdullahi, Abdullah Emin Akay* 94

Tree Diameter Measurement Using a Smartphone with Laser Technology. *İnanç Taş, Hajri Haska, Abdullah Emin Akay, Halil İbrahim İnce, Olsi Miraci* 100

Use of Environmentally Friendly Logging Operations in The Concept of Small Scale Forestry. *Hajri Haska, Sinem İnan, Abdullah Emin Akay* 106

The Biodiversity of Georgian Forests and the Current Situation. *Rezo Vasadze, Guguli Dumbadze, Sesili Gatenadze* 112

An Evaluation of Diameter Measurement Techniques: Comparing Calipers, Laser Devices, and the Measure Application. *Ensar Tuğralp Kanmaz, Emre Kilinçarslan, Burhan Gencal* 121

Log Volume Measurement Using a LiDAR-Enabled Smartphone. *Hasan Bilgin, Burhan Gencal, Turan Sönmez, Emre Kilinçarslan, İnanç Taş* 131

Assessment of PM10 Exposure in Chainsaw Operators During Tree Felling. *İnanç Taş* 141

Calculation of Log Stack Volume Using Spatial Photos. *İnanç Taş, Burhan Gencal, Emre Kılınçarslan* 146

Assessing Windthrow Impact in Kastamonu Forests: Environmental Factors and Sentinel-2A Imagery Analysis. *Abdurrahim Aydın, Tunahan Çınar, Nihat İşlek* 151

Development of Low-Cost IR Forest Scanner. *Burak Türkay, Abdurrahim Aydın* 169

Performance Analysis in Timber Loading Operations with A Tractor-Mounted Single-Gear 179

Front Loader. *Saliha Ünver, H. Hulusi Acar*
Assessment of Urban Green Areas Using i-Tree Canopy. *Abdulwasa Abdiwali Hassan, Abdullah Emin Akay, Zennure Uçar, Neşat Erkan* 188
Stump Harvesting Operations: Examples from the Mediterranean Region. *Mehmet Eker, Raffaele Spinelli, Hakan Durgun* 194
Key Issues That Need to be Addressed for Successful Biomass Harvesting and Utilization. *Mehmet Eker, Hakan Durgun, Han-Sup Han* 204
An Assessment on the Methods of Unit Price Calculation Procedure for Wood Harvesting. *Mehmet Eker, Selami Cilan, Natascia Maganotti, Hakan Durgun* 216
Identification of Potential Hydraulic Structures on Forest Roads Using ArcGIS® ModelBuilder. *Taha Yasin Hatay, Selçuk Gümüş* 228
Assessment of Machine-Based Hazards and Risks in Forestry Transport Works Using HRNS and TOPSIS Methods. *Hafiz Hulusi Acar, Tolga Barişik* 237
Determination of Soil Deformation with Unmanned Aerial Vehicles in Logging Activities with Agricultural Tractors. *Ebru Bilici, Halit Büyüksakallı, Abdullah Emin Akay* 246
Redesigning Administrative Measures on Wildlife: Case Study of Deer Management in Kumamoto Prefecture, Japan. *Junna Iwano, Noriko Sato, Takahiro Fujiwara* 254
UAV-Based Temporal Change Detections in an Open-pit Mine Using Python. *Hakan Durgun, Arif Ögke, H. Oğuz Çoban* 260
Comparing Manual and Numerical Methods for Forest Road Design. *Hakan Durgun, Serhat Oğuz Şergi, Mehmet Eker* 271
Estimating Sediment Yield from a Road Network by Using a GIS-Based Sediment Prediction Model. *Esin Erdoğan Yüksel, Ömer Faruk Karan, Abdullah Emin Akay, Ebru Bilici* 280
Analysis of Climate Change Variability Over Amasya Merzifon Forest Areas. *Mehmet Cetin* 289
Assessment of Soil Contamination in Urban Forest Areas of Samsun City. *Ilknur Zeren Cetin* 295
Assessment of Compatibility of Forestry Machines with Soils Based on an Integral Indicator. *Yuliya Misuna, Pavel Protas* 302
Modelling of Gas Dispersion in Forests and Usage of Actual Dispersion Models in Forest Areas: A Software Assisted Study of a Likely Outflow Scenario. *H. Hulusi Acar, Tahsin Aykan Kepekli* 311
.

# Utilizing Decision Trees Models for Machine Selection and Optimal Deployment in Forest Logging Planning

**Mustafa Acar[1*], Selçuk Gümüş[2]**

[1]Artvin Çoruh University, Faculty of Forestry, Artvin, Türkiye
[2]Karadeniz Technical University, Faculty of Forestry, Trabzon, Türkiye
*mustafa.acar@artvin.edu.tr

## Abstract

Logging is challenging and renewable for forest areas located in mountainous and variable terrains. Effective planning and sustainable management are crucial for optimizing the economic benefits of these forests. Expanding forest areas offers advantages in terms of time and cost by selecting machinery that is appropriate for the land conditions and utilizing these machines efficiently. However, logging planning is particularly challenging for complex and variable forest areas. These studies have become feasible with the development and application of artificial intelligence tools across nearly every field today. This study utilized the decision trees method to reveal the logging planning of a forest enterprise. The research was conducted in 7 production sections as part of the logging planning for the current year in the Taşlıca Forest Enterprise, which was designated as the study area. Within the scope of the studies, slope, skidding distance, tree type, stand canopy, skidding barrier and living cover were taken into account as land data, and the amount of stamped product was taken into account as forest management plan data. Based on the results obtained from the model created using the Decision Tree method, a logging planning was developed. This plan includes the estimation of the extraction method in the compartments, the completion time of the work in terms of days, and the approximate cost of the wood raw material production work.

***Keywords:*** *Logging, decision making, artificial intelligence, logging planning*

## 1. Introduction

The growing demand for wood raw materials places considerable strain on forestry operations, which are inherently complex and expensive. Among the stages involved in wood raw material production, the extraction phase is particularly significant, as it not only contributes heavily to costs but also poses the greatest risk of damage to both the wood and the forest environment. Not only the trees designated for production but also those outside the scope of the production plan are adversely affected by these operations (Spinelli, 1999; Sowa and Stanczykiewicz, 2004). This phase, known as primary transportation, plays a crucial role in ensuring the sustainable use of forests and maintaining the quality of wood products. Therefore, minimizing damage during the production process is essential for sustainability. Technological advancements have led to the development of more efficient planning strategies for managing the complexities of forestry operations. The use of artificial intelligence (AI) techniques, now widely applied in various sectors (Minowa, 2005), offers several benefits for forestry, including cost savings, reduced environmental impact, and improved operational efficiency through optimized wood raw material production. As AI technologies continue to advance, their integration into forestry practices will be instrumental in promoting sustainable forest management and supporting more effective decision-making processes.

This study aims to apply multi-criteria decision-making using decision tree methods, a branch of machine learning and an integral part of artificial intelligence. Decision trees provide a structured and efficient approach for tackling complex decision-making processes by simultaneously evaluating multiple criteria (Quinlan, 1993). Their use in this context enables systematic analysis of the factors influencing outcomes, thereby improving the accuracy and efficiency of decision-making in forestry management (Breiman et al., 1984).

The use of artificial intelligence in selecting machinery for wood raw material extraction in forest areas has been underexplored in current research. In this study, a decision tree model is applied to assess machine efficiency, estimate production costs, and predict operation times in forestry production activities. Decision trees offer a robust framework for evaluating machine performance under various conditions, resulting in more accurate predictions and more informed decision-making (Breiman et al., 1984). The effective use of machinery in forestry operations is vital not only for reducing costs but also for optimizing the entire production process. The artificial intelligence technique used in cost estimation of harvesting processes has yielded more accurate results compared to traditional methods (Proto et al., 2020).

A recent study by Acar (2023) demonstrated 100% prediction accuracy in planning models utilizing the decision tree method, highlighting the method's exceptional capability in forecasting and decision-making for forestry operations. This finding reinforces the reliability and precision of decision trees as a valuable tool for optimizing planning and machinery selection in complex operational environments.

In this study, a decision tree model was developed using data from 500 field samples. Expanding the database in monitoring studies facilitates the application of supervised learning techniques for modelling and prediction (Polowy and Molińska-Glura, 2023). Software tools such as ArcGIS 10.2, Google Earth Pro, and Microsoft Office Excel were employed to construct the model. The final decision tree model was then transformed into a mobile application, enhancing its accessibility and practical use.

## 2. Materials and Methods

### 2.1. Study Area

Taşlıca Forest Enterprise, under the jurisdiction of the Artvin Regional Forest Directorate, was selected as the study area. Within Taşlıca's boundaries, 7 compartments are scheduled for production in 2024. No assessment was conducted for Compartment 12, as the use of machinery was not anticipated, and no machine selection was made by the model.

Taşlıca's forest area has between 570-2296 m elevation, it is located between 41° 06' 56"- 41° 10' 58" North latitude and 41° 42' 05"- 41° 46' 28" East longitude (Figure 1). The total forest area of Taşlıca Forest Enterprise is 2296.3 ha, the normal closed forest area is 2063.2 ha and the area with production function is 1598.2 ha (GDF, 2021).

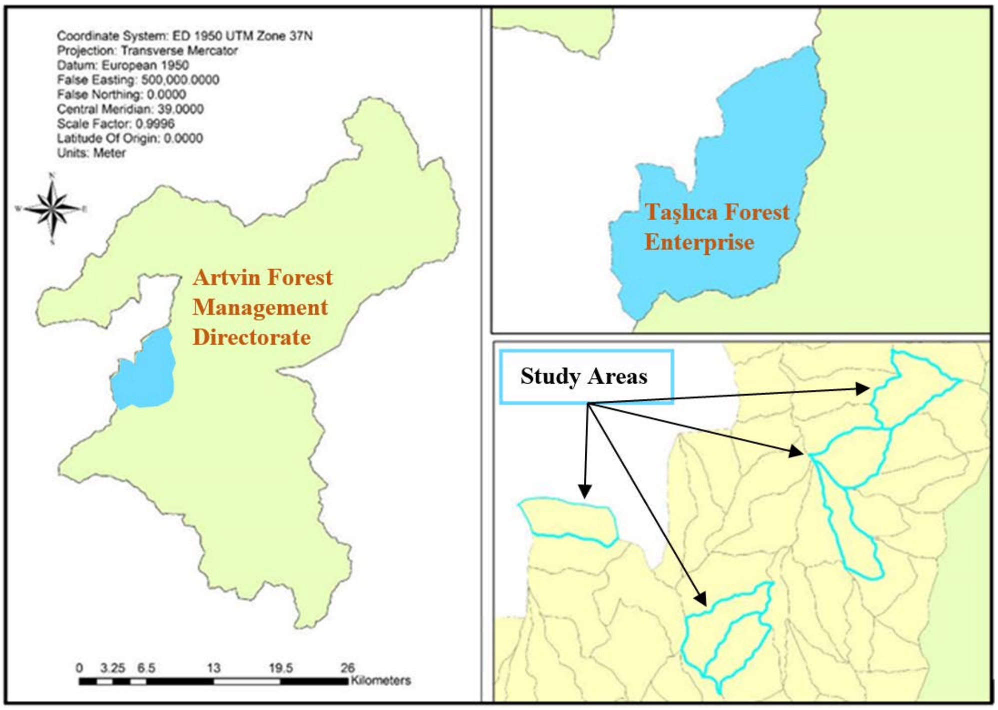



Figure 1. Taşlıca Forest Enterprise

### 2.2. Data Collection Method

The collection of data to be used in the decision tree model was carried out in 3 stages. These are management plans, GIS and field measurements, respectively. Firstly, the data on tree species, terrain slope, growth stage, canopy density, and volume of stamped trees decided for cutting were obtained from the forest management plans. Secondly, a terrain model was developed using ArcGIS 10.2 based on data obtained from the forest management plan and the forest administration. The resulting study areas were converted into KML format and imported into the open-source program Google Earth Pro (Figure 2a). In this platform, the maximum yarding distances and the extraction direction from the compartment were determined in relation to forest roads (Figure 2b). Subsequently, the third phase of data collection, consisting of field measurements and observations, was conducted. Site visits were made to the study areas to assess soil dryness, presence of understory vegetation, and potential terrain obstacles.

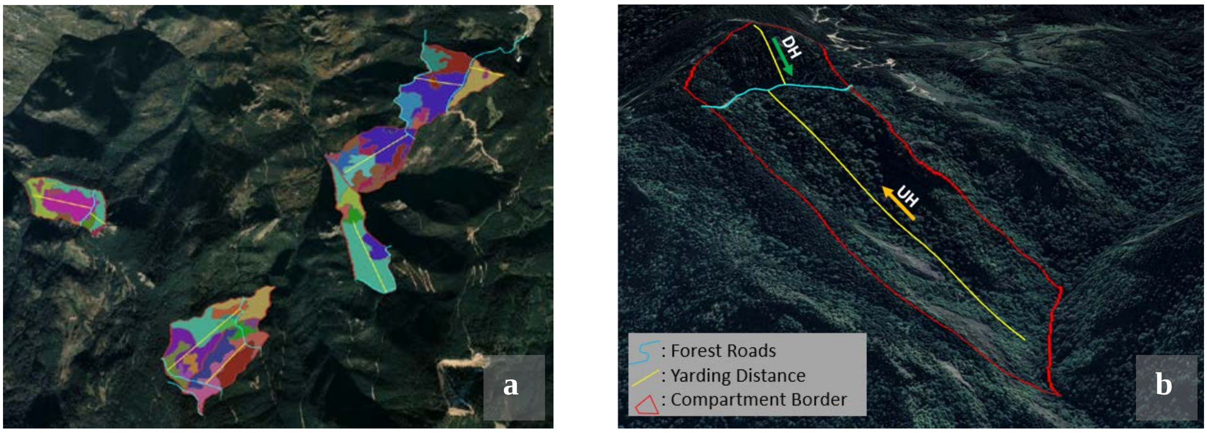



Figure 2. Study areas (a) and a sample extraction unit (b)

### 2.3. Data Using

The data obtained from the three phases were used to create a dataset in Microsoft Excel. This dataset was then utilized to generate a Decision Tree using the RapidMiner software. A decision tree has been constructed using 500 sample data. Within the scope of the studies, the following land attributes were taken into account: slope, yarding distance, tree species, stand canopy, skidding barriers, and ground cover. The quantity of extracted wood was used as the primary data for the forest management plan.

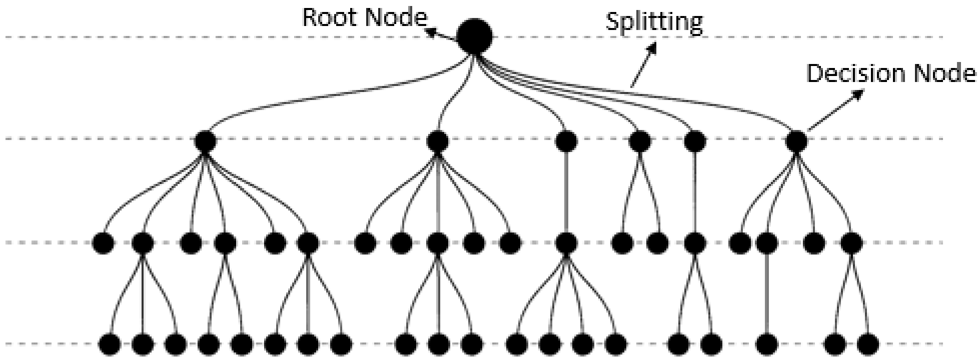



Figure 3. Decision tree sample

## 3. Results and Discussions

The data in columns 1-4 were sourced from the forest management plans (Table 1), while the data in columns 5-7 were obtained from GIS analysis. Lastly, the data in columns 8-10 were derived from field measurements and observations. In addition to these, the number of trees stamped for production, as provided by the forest administration, is presented in the column following the compartment number. The production quantities in column 5 were determined based on the extraction direction from the compartment.

Table 1. Forest management and planning data

| Compartment No | Harvest Volume ($m^3$) | Slope (%) | Tree Species ** | Growth Stage | Density |
|---|---|---|---|---|---|
| 11 | 1135 | 52 | C | c | 3 |
| 22 | 1538 | 45 | M | c | 3 |
| 23 | 1112 | 55 | C | c | 3 |
| 29 | 501 | 71 | M | d | 3 |
| 37 | 2853 | 53 | M | d | 3 |
| 38 | 1401 | 50 | C | d | 3 |
| TOPLAM | 8540 | | | | |

**C : Coniferous
**M : Mixed

Data obtained from the forest administration and management plans were analyzed using ArcGIS 10.2, and the study areas were converted into KML format and imported into Google Earth Pro. Subsequently, based on the condition of the forest roads, the hauling/skidding distances and extraction directions from the compartment were determined as shown below

(Table 2). The harvest volumes were determined based on the extraction directions from the compartment.

Table 2. Data from GIS

| Comp. No | Harvesting Volume (m³) | Max Yarding Distance (m) | Extraction Direction ** |
|---|---|---|---|
| *11* | 500 | 450 | UH |
| | 635 | 325 | DH |
| *22* | 1538 | 790 | UH |
| *23* | 1112 | 730 | UH |
| *29* | 400 | 780 | UH |
| | 101 | 220 | DH |
| *37* | 2853 | 750 | UH |
| *38* | 1401 | 485 | UH |
| *TOTAL* | 8540 | | |

**UH : Uphill
**DH : Downhill

Measurements and observations for the study areas were conducted through field visits. Conditions such as soil surface, understory vegetation, and terrain obstacles were examined, and the results are presented in Table 3. All of this data was processed within the mobile application that utilizes the decision tree model, resulting in the final "decision" column (Figure 4).

Table 3. Measurement-Observation Data from Study Areas

| Compartment No | Soil Condition | Ground Cover | Terrain Obstacle |
|---|---|---|---|
| 11 | Dry | Yes | Yes |
| | Dry | No | Yes |
| 22 | Dry | Yes | Yes |
| 23 | Dry | No | Yes |
| 29 | Dry | Yes | Yes |
| | Dry | No | No |
| 37 | Dry | Yes | No |
| 38 | Dry | No | Yes |

| Compartment No | Production Volume (m³) | 1<br>Slope % | 2<br>Tree Species | 3<br>Growth Stage | 4<br>Density | 5<br>Production Volume (m³) | 6<br>Max Yarding Distance (m) | 7<br>Extraction Direction | 8<br>Soil Condition | 9<br>Ground Cover | 10<br>Terrain Obstacle | DECISION *** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 1135 | 52 | C | c | 3 | 500 | 450 | UH | Dry | Yes | Yes | MRSL |
| | | | | | | 635 | 325 | DH | Dry | No | Yes | MRSL |
| 22 | 1538 | 45 | M | c | 3 | 1538 | 790 | UH | Dry | Yes | Yes | MRSL |
| 23 | 1112 | 55 | C | c | 3 | 1112 | 730 | UH | Dry | No | Yes | MRSL |
| 29 | 501 | 71 | M | d | 3 | 400 | 780 | UH | Dry | Yes | Yes | MRSL |
| | | | | | | 101 | 220 | DH | Dry | No | No | MP |
| 37 | 2853 | 53 | M | d | 3 | 2853 | 750 | UH | Dry | Yes | No | MRSL |
| 38 | 1401 | 50 | C | d | 3 | 1401 | 485 | UH | Dry | No | Yes | MRSL |
| TOPLAM | 8540 | | | | | 8540 | | | | | | |

***MRSL: Medium-Range Sky Line
***MP: Man Power

Figure 4. The data processed within the mobile application

As a result of data collection, the decision class was determined using the decision tree model. Based on the decision class, data on cost and completion time were subsequently obtained. The mobile application developed for this purpose was utilized to obtain these results (Figure 5). This work has been carried out to optimize the usage of machinery. Therefore, the MP section of partition number 29 has not been considered. In that section (MP), Manpower or a logline system could be used.

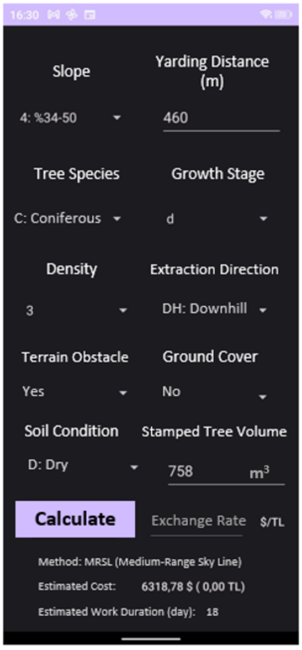



Figure 5. The mobile application interface

## 4. Conclusions

Due to the steep terrain of the forested areas in the Eastern Black Sea region, the usage of skyline yarders is crucial. At the Taşlıca Forest Enterprise, machine-based harvest of wood approximately 8,440 m³ has been planned. With medium-ranged skylines, this harvesting requires 263 work-days. Sections 11 and 38 can utilize the Tajfun MOZ 500 skyline for UH yarding. For sections where the distance exceeds 500 meters and DH operation is performed, the URUS MIII skyline, which is used in the region, can be employed. As a result, Tajfun MOZ 500 (44 days or 352 hours) and URUS MIII (219 days or 1752 hours) can complete the wood harvesting. The total production cost has been calculated as $99,313.71. The daily production cost is $377.62 per day, and the daily production volume is 32.09 m³ per day.

**References**

Acar, M. 2023. Utilizing Decision Tree Models for Estimating Wood Extraction Methods. PhD. Thesis, Karadeniz Technical University, The Graduate School of Natural and Applied Sciences, Trabzon, Türkiye. 150 p.

Breiman, L., Friedman, J.H., Olshen, R.A., Stone, C.J. 1984. Classification and Regression Trees. Wadsworth & Brooks/Cole Advanced Books & Software.

GDF 2021. General Directorate of Forestry, Taşlıca Forest Enterprise, Management Plan.

Minowa, Y. 2005. Classification Rules Discovery from Selected Trees for Thinning with the C4.5 Machine Learning System. J. For. Res., 10: 221–231.

Polowy, K., Molińska-Glura, M. 2023. Data Mining in the Analysis of Tree Harvester Performance Based on Automatically Collected Data. Forests, 14: 165.

Proto, A. R., Sperandio, G., Costa, C., Maesano, M., Antonucci, F., Macri, G., Scarascia Mugnozza, G., Zimbalatti, G. 2020. A Three-Step Neural Network Artificial Intelligence Modelling Approach for Time, Productivity and Costs Prediction: A Case Study in Italian Forestry. Croat. J. For. Eng., 41: 35–47.

Quinlan, J.R. 1993. C4.5: Programs for Machine Learning. Morgan Kaufmann Publishers.

Sowa, J.M., Stanczykiewicz, A. 2004. Analysis of Injuries Occurring in Trees as a Result of Timber Harvesting. Forest Engineering: New Techniques, Technologies and The Environment, 329-337 P, Lviv, Ukraine.

Spinelli, R. 1999. The Environmental Impact of Thinning: More Good Than Bad?. In: Proc IUFRO 3.09.00 Harvesting and Economic of Thinning, 136-143.

# Productivity Calculation of Serial and Parallel Production Systems in Forestry

**Tetsuhiko Yoshimura[1*], Yasushi Suzuki[2], Noriko Sato[3]**

[1]Shimane University, Faculty of Life and Environmental Sciences, Matsue 690-8504, Japan
[2] Kochi University, Faculty of Agriculture and Marine Science, Nankoku 783-8502, Japan
[3] Kyushu University, Faculty of Agriculture, Department of Agro-Environmental Sciences, Fukuoka 819-0395, Japan
*t_yoshimura@life.shimane-u.ac.jp

## Abstract

Forest machines often work in combination and can be used in series or in parallel while harvesting trees. The serial production system needs the longer production time while the parallel production system needs the shorter one. Despite the shorter production time, the parallel production system needs more workers at the same time than the serial production system. In addition, the parallel production system has the difficulty of synchronizing the operations of two or more machines and their operators. Productivity is an important indicator to evaluate the efficiency of forest harvesting operations. Therefore, in this study, we calculated the system productivity of serial and parallel production systems. We also constructed the production models of forest harvesting systems using system dynamics and calculated the productivity according to the performance of each forest machine used in combination. As a result, we were able to accurately determine the total productivity of the CTL operations and the required storage size for felled and processed logs.

***Keywords:*** *Forest machine, productivity calculation, production system, system dynamics*

## 1. Introduction

Productivity, defined as the rate of product output per unit of time for a given production system (Liski et al., 2002), is an important indicator for evaluating the efficiency of forestry operations. Today, most forest harvesting is done with forest machines, and their efficiency depends not only on the performance of each machine, but also on how they are used in combination. The most common harvesting system using a harvester and forwarder combination is the cut-to-length (CTL) system. For example, Ackerman et al. (2022) evaluated the feasibility of using a Malwa 560C combination harvester/forwarder in South Africa. Many other combinations other than the CTL are possible, and Papandrea et al. (2024) investigated the combination of a tractor-mounted tower yarder (Valentini V400) with a clambunk skidder (Timberjack 1010D), aiming to examine the viability and develop the operational efficiency of the two-stage extraction system and to define the time, log volume extracted per unit by the yarder and the clambunk, and the yarding and skidding costs in a deciduous stand in Bulgaria. Considering the importance of a combined productivity assessment, this study classifies forest production systems as serial and parallel, compares these two production systems based on the productivity calculations, and presents the system dynamics models for flexible productivity calculations.

## 2. Materials and Methods

### 2.1 System Productivity Calculation for the Serial Production Systems

In the serial system the production processes are performed sequentially. For example, in the CTL system, after all the trees have been felled and processed by the harvester, the forwarding process begins (Figure 1). As shown in Yoshimura et al. (2023), the total production time for the serial system ($T_0$) is expressed by the following equation:

$$T_0 = T_1 + T_2 \tag{1}$$

where $T_0$ is the total production time of the serial production system, $T_1$ and $T_2$ are the production times of the harvesting and forwarding processes, respectively. Then, the production rate of the serial production system ($R_0$) is expressed by the following equation:

$$R_0 = \frac{V}{T_0} = \frac{V}{T_A + T_B} = \frac{V}{\frac{V}{R_1} + \frac{V}{R_2}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \tag{2}$$

where $V$ is the total production volume, and $R_1$ and $R_2$ are the production rates for the harvesting and forwarding processes, respectively.

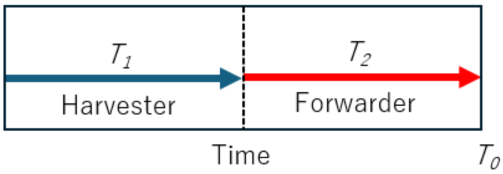



Figure 1. Example of the serial production system

### 2.2 Productivity Calculation for the Parallel Production Systems

Conversely, in the parallel system, the production processes are carried out simultaneously, either partially or completely (Figure 2). As shown in Yoshimura et al. (2023), the total production time for the parallel system ($T_s$) is expressed by the following equation:

$$T_s = s \times T_0 \tag{3}$$

where $T_s$ ($<T_0$) is the total production time for the parallel production system and $s$ ($<1$) is the time-saving rate. Here, $s$ is equal to 1 for the serial production system. In Figure 2, $T_1$ and $T_2$ are expressed by the following equations:

$$T_1 = u_1 \times T_s \tag{4}$$

$$T_2 = u_2 \times T_s \tag{5}$$

where $u_1$ ($<1$) and $u_2$ ($<1$) are the ratios of the production time for the harvesting and forwarding processes, respectively, to the total production time for the parallel production system ($T_s$). Then, the following equation holds under the above conditions:

$$s = \frac{T_s}{T_0} = \frac{T_s}{T_1 + T_2} = \frac{T_s}{u_1 T_s + u_2 T_s} = \frac{1}{u_1 + u_2} \tag{6}$$

The production rate of the parallel production system ($R_s$) is expressed by the following equation:

$$R_s = \frac{V}{T_s} = \frac{V}{s \times T_0} = \frac{V(u_1 + u_2)}{T_0} = \frac{V(u_1 + u_2)}{\frac{V}{R_0}} = R_0(u_1 + u_2) \qquad (7)$$

In Equation (7), $u_1+u_2>1$ holds for the parallel production system, and $u_1+u_2=1$ holds for the serial production system, and the following equation holds:

$$\frac{u_1}{u_2} = \frac{\frac{T_1}{T_s}}{\frac{T_2}{T_s}} = \frac{T_1}{T_2} = \frac{\frac{T_1}{V}}{\frac{T_2}{V}} = \frac{\frac{1}{R_1}}{\frac{1}{R_2}} = \frac{R_2}{R_1} \qquad (8)$$

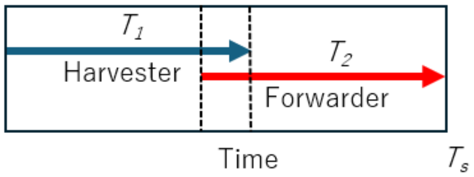



Figure 2. Example of the parallel production system

### 2.3 Advantages and Disadvantages

The advantage of the serial production system is that the forest harvesting operations can be planned and carried out in a simple and flexible way. The disadvantage of the serial production system is that trees or logs have to be stored until the next process: logs have to wait for the forwarder to transport them. On the other hand, the parallel production system can shorten the total production time, while the forest harvesting systems of it can be more complicated.

## 3. Results and Discussion

### 3.1 Productivity calculation

The Productive Machine Hour (PMH) is commonly used as the unit of productivity for mechanized forest harvesting operations. The PMH represents the time during which the machine actually performs work, and this excludes time lost due to mechanical and non-mechanical delays from the Scheduled Machine Hours (SMH), which includes all the time the machine is scheduled to work (Picchio et al., 2020). While the PMH is widely used for systems consisting of a single machine and operator, the Productive System Hour (PSH) includes two or more machines or sequential operations required to complete the task (Talbot et al., 2015). The use of the $m^3$/PSH is appropriate as a unit of productivity unit when multiple forest machines are used in combination. As far as we know, Stampfer (1999) was the first to use the PSH concept.

Assuming that the productivity of a harvester and a forwarder is 15 $m^3$/PMH and 20 $m^3$/PMH, respectively, the total productivity of the CTL system in the serial production ($R_{serial}$) can be calculated as follows:

$$R_{serial} = \frac{1}{\frac{1}{15} + \frac{1}{20}} = 8.57\ (\mathrm{m^3/PSH}) \qquad (9)$$

When the ratios of the production time for the harvesting and forwarding processes are 0.8 and 0.6, respectively, the total productivity of the CTL system in the parallel production ($R_{parallel}$) can be calculated as follows:

$$R_{parallel} = R_{serial} \times (0.8 + 0.6) = 12.00\ (\mathrm{m}^3/\mathrm{PSH}) \tag{10}$$

The total productivity of the CTL system in the parallel production ($R_{parallel}$) is maximized and calculated as in Equation (11) when the ratios of the production time to the total production time for the harvesting and forwarding processes are 1.00 and 0.75, respectively.

$$R_{parallel} = R_{serial} \times (1.00 + 0.75) = 15.00\ (\mathrm{m}^3/\mathrm{PSH}) \tag{11}$$

As a result, the total productivity of the CTL system in the parallel production ranges between 8.57 to 15.00.

### 3.2 Application of the System Dynamics Simulation

We used the system dynamics simulation to calculate the total productivity of the CTL system. The idea of system dynamics was developed by Professor Jay Forrester of the Massachusetts Institute of Technology in 1956. It provides methods and tools to model and analyze complex and dynamic systems and to help people make better decisions when faced with such systems. Figure 3 shows a model of the CTL system constructed using Stella software (isee systems). In this model, 1,500 $\mathrm{m}^3$ of logs in the stock of the standing trees are given as an initial value, and it is assumed that the productivity of a harvester and a forwarder is 15 $\mathrm{m}^3$/PMH and 20 $\mathrm{m}^3$/PMH, respectively. In the parallel production system, the forwarding process begins 50 hours after the start of felling and processing.

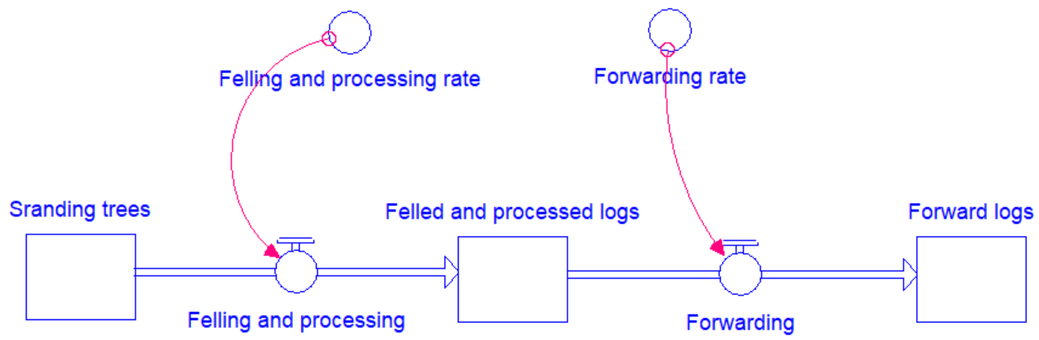



Figure 3. A system dynamics model of the CTL system using Stella software

Figures 4, 5 and 6 show the change in the volume of standing trees, felled and processed logs, and forwarded logs, respectively, in the parallel production system. According to these figures, the CTL operations in this model are completed in 125 hours for 1,500 $\mathrm{m}^3$ of logs. As a result, the total productivity of the CTL operations is calculated to be 12 $\mathrm{m}^3$/PSH, which is the same as shown in Equation (10). Figure 5 shows that the volume of felled and processed logs reaches a maximum of 750 $\mathrm{m}^3$ after 50 hours from the start of the CTL operation. This means that the storage capacity for the logs felled and processed by the harvester must be at least 750 $\mathrm{m}^3$ in the parallel production system.

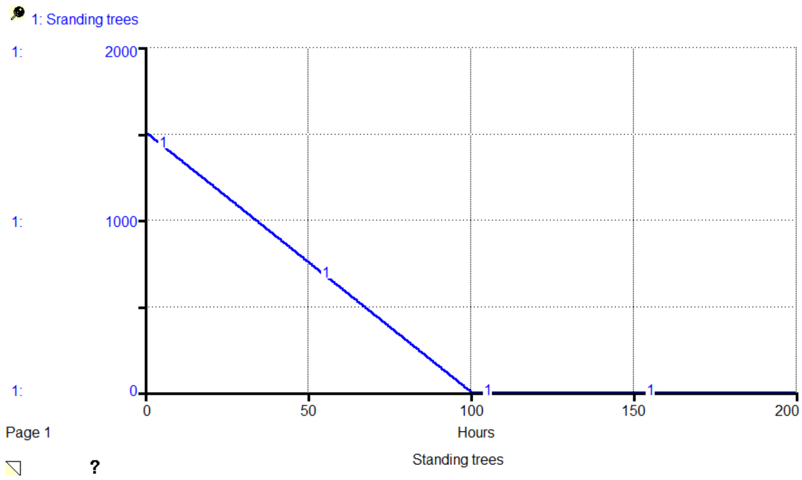



Figure 4. Change in the volume of standing trees

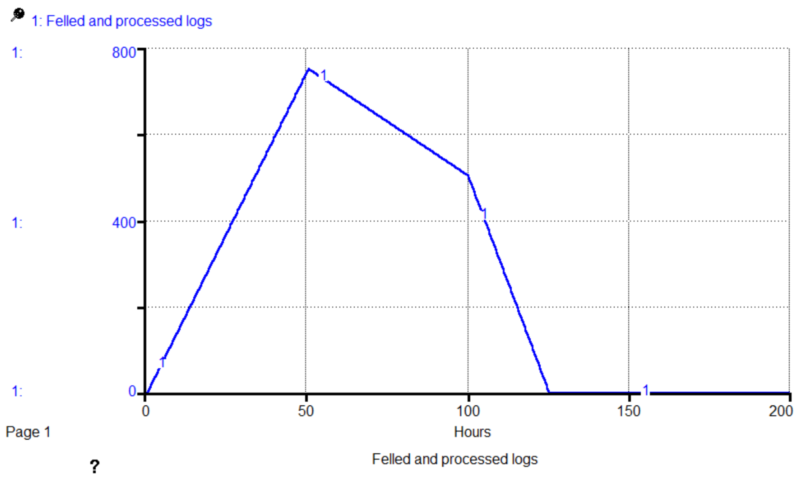



Figure 5. Change in the volume of felled and processed logs

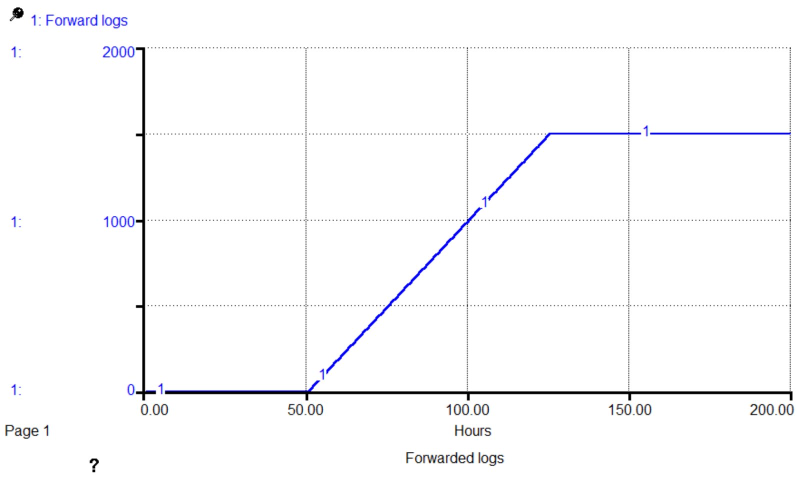



Figure 6. Change in the volume of forwarded logs

## 4. Conclusions

We calculated the system productivity of serial and parallel production systems in forest harvesting operations by constructing the production models using the system dynamics according to the performance of each forestry machine used in combination. As a result, we were able to accurately determine the total productivity of the CTL operations and the required storage size for felled and processed logs. Further studies will be conducted for different combinations of forest machines.

**Acknowledgements**
This work was supported by JSPS KAKENHI Grant Numbers 21H03672, 22K05747 and 24H00781.

**References**

Ackerman, S.A., McDermid, H., Ackerman, P., Terblanche, M. 2022. The effectiveness of a small-scale combination harvester/forwarder in industrial plantation first thinning operations. Int. J. For. Eng. 33: 56–65.

Liski, E.; Jounela, P., Korpunen, H.; Sosa, A., Lindroos, O., Jylhä, P. 2020. Modeling the productivity of mechanized CTL harvesting with statistical machine learning methods. Int. J. For. Eng. 31: 253–262.

Papandrea, S.F., Stoilov, S., Cataldo, M.F., Petkov, K., Angelov, G., Zumbo, A., Proto, A.R. 2024. Evaluation of Productivity and Cost Analysis on a Combined Logging System. Forests, 15: 980.

Picchio, R., Venanzi, R., Di Marzio, N., Tocci, D., Tavankar, F. 2020. A comparative analysis of two cable yarder technologies performing thinning operations on a 33 year old pine plantation: A potential source of wood for energy. Energies, 13: 5376.

Stampfer, K. 1999. Influence of terrain conditions and thinning regimes on productivity of a track-based steep slope harvester. In Proceedings of the International Mountain Logging 10th Pacific Northwest Skyline Symposium, Corvallis, OR, USA, 28 March–1 April 1999.

Talbot, B., Stampfer, K., Visser, R. 2015. Machine function integration and its effect on the performance of a timber yarding and processing operation. Biosyst. Eng. 135: 10–20.

Yoshimura, T., Suzuki, Y., Sato, N. 2023. Assessing the Productivity of Forest Harvesting Systems Using a Combination of Forestry Machines in Steep Terrain. Forests, 14: 1430.

# Assessing Forest Fire Susceptibility and Potential Severity in the Wildland-Urban Interface (WUI) with Machine Learning and Google Earth Engine: Case of Izmir Regional Directorate

**Remzi Eker[1*], Kamber Can Alkiş[2], Ahmet Açıl[3], Abdurrahim Aydın[4]**

[1]İzmir Katip Çelebi University, Faculty of Forestry, 35620 İzmir, Türkiye
[2]İzmir Regional Directorate of Forestry, 35530 İzmir, Türkiye
[3]Karabük University, Faculty of Forestry, 78050 Karabük, Türkiye
[4]Düzce University, Faculty of Forestry, 81620 Düzce, Türkiye
*remzi.eker@ikc.edu.tr

**Abstract**

This study presents a method utilizing Machine Learning (ML) and Google Earth Engine (GEE) to evaluate forest fire susceptibility and potential fire severity in the Wildland Urban Interface (WUI) of the Izmir Regional Forest Directorate (RFD) in Türkiye. Precise mapping of WUI areas and assessing fire susceptibility and severity are crucial for advanced forestry, particularly in precision forestry. Initially, WUI areas—both WUI-intermix and WUI-interface—were mapped using a Python-based algorithm in ArcMap. A forest fire susceptibility map was then created by integrating 15 influencing factors with the PyCaret AutoML framework, which compares 14 ML algorithms. For mapping potential fire severity, a GEE-based algorithm was employed, utilizing the Random Forest (RF) method with 19 driving factors. The resultant maps were used to evaluate fire susceptibility and potential fire severity in the WUI areas. Results indicate that 2.5% of the Izmir RFD is classified as WUI-intermix, while 5.1% is WUI-interface. It was observed that 36.0% of WUI-intermix areas could potentially experience moderate to high severity fires, with 21.7% of WUI-interface areas falling into similar categories. Regarding fire susceptibility, 88.6% of WUI-intermix areas were identified as high and very high susceptible, while 82.0% of WUI-interface areas exhibited similar levels. To conclude, mapping WUI areas and assessing their fire susceptibility and potential severity offer invaluable insights for forest managers to combat forest fires and plan operations effectively in high-risk areas.

***Keywords:*** *Forest fire susceptibility, GEE, machine learning, potential fire severity, WUI*

## 1. Introduction

As a novel approach to enhance forest management, precision forestry focuses on planning and implementing site-specific forest management activities to enhance wood product quality, minimize waste, boost profits, and uphold environmental quality (Taylor et al., 2002). A key aspect of precision forestry lies in integrating modern technologies such as instrumentation, mechanization, and information technologies (Kovacsova and Antalova, 2010). Information technologies facilitate data-driven management practices and support scientific exploration, playing a vital role in improving decision-making processes to meet forest management objectives while mitigating negative environmental impacts.

Common tools in precision forestry include a combination of GIS (Geographical Information System), GPS/GNSS (Global Positioning System/Global Navigation Satellite System), and RS

(Remote Sensing) technologies. Particularly for environmental conservation, there is an urgent need for comprehensive information on disturbances like forest fires. This includes crucial data about Wildland Urban Interface (WUI) zones, where human infrastructure intersects with flammable forest vegetation (Bar-Massada et al., 2013). WUI zones represent the interface between buildings and wildland vegetation (Radeloff et al., 2005), making WUI maps invaluable for identifying areas at high risk of forest fire hazards (Carlson et al., 2022). Forests in WUI areas are experiencing significant changes due to various disturbances, including fire, drought, insect outbreaks, disease, deforestation, and climate change (Keenan et al., 2015). These disturbances have a pronounced impact on populations residing in WUI areas (Sankey et al., 2024). Sankey et al. (2024) highlighted that forest canopy cover, tree density, patch sizes, and mean tree canopy height can be mitigated through meticulous mechanical thinning to reduce active crown fire risks. Therefore, it is crucial to accurately map WUI areas using reliable methods and provide base maps to support decision-making for foresters in forest operations.

Current literature includes various WUI mapping studies conducted at different scales, ranging from regional to global. For instance, Modugno et al. (2016) developed a European WUI map, while Schug et al. (2023) produced a global WUI map. In Türkiye, Aksoy et al. (2023) recently assessed fire risk in WUI regions on the European side of Istanbul using machine learning and GIS data. Additionally, Darques (2015) conducted a study in Türkiye aiming to evaluate city-wildland/wildfire relationships across the Mediterranean Basin based on MODIS data.

In this study, we applied a WUI mapping a similar methodology proposed by Bar-Massada et al. (2013) to the Izmir Regional Forest Directorate (RFD) and evaluated it in terms of forest fire susceptibility and potential fire severity. We utilized a forest susceptibility map created by Eker et al. (2024) using the PyCaret AutoML framework. Additionally, a country-scale potential fire severity map developed by Eker and Aydın (2024) using RF on the GEE platform was employed. This research aimed to assess WUI areas, specifically categorized as WUI-intermix and WUI-interface, for the first time, considering both forest fire susceptibility and potential fire severity within the selected study area in Türkiye.

## 2. Material and Methods

### 2.1 Study Area

The study area selected for this research is the Izmir RFD, one of the 30 forest regional directorates in Türkiye. Situated in the northern longitude range of 39°35’38” – 37°52’30” and eastern latitudes of 26°11’42” – 28°52’28” (Fig. 1), Izmir RFD encompasses almost one-third of the Aegean region of Türkiye, including the cities of Izmir and Manisa. Covering a total area of 2,509,336 hectares, the region's forests constitute approximately 46% of the total area. Izmir RFD stands out as one of the vulnerable forest regions to various disturbances in Türkiye, with a particular emphasis on forest fires (Akyuz and Kucukosmanoglu 1997, Kucukosmanoglu and Uzmez 2019). According to forest fire statistics from the General Directorate of Forestry (GDF) of Türkiye for the year 2022, the data reveals that 23,938 hectares of areas have been burned between 2004 and 2022 in Izmir RFD (GDF, 2024).

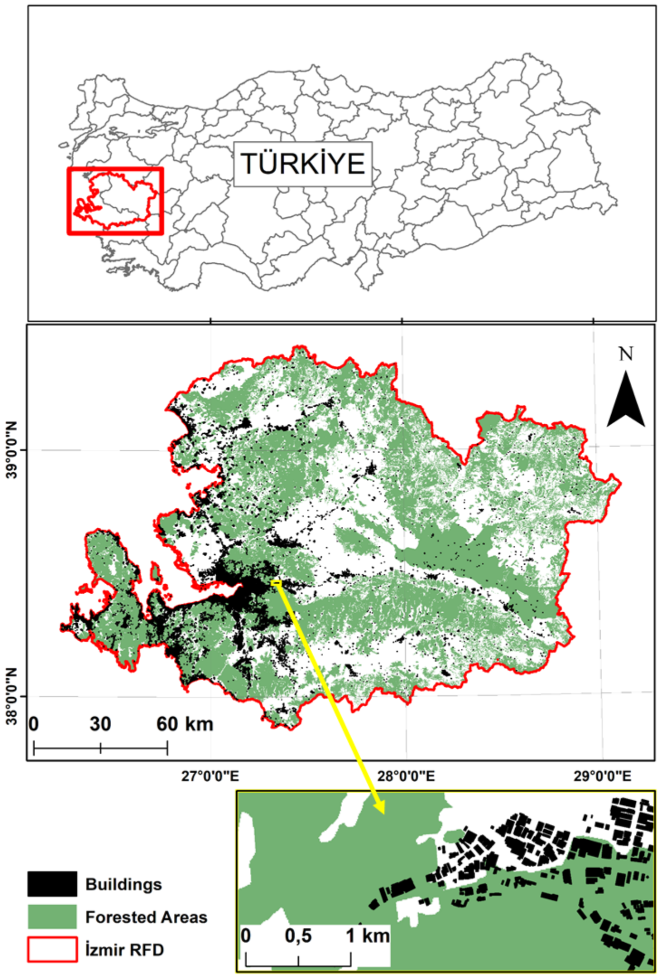



Figure 1. Location map of Izmir RFD

**2.2 WUI Mapper (Türkiye) Toolbox**

The WUI Mapper (Türkiye) algorithm is a Python-based tool developed to run within ArcMap, designed specifically for mapping WUI areas in Türkiye (Figure 2). The workflow follows the similar approach outlined by Bar-Massada et al. (2013), using parameters that define standard WUI areas. To be classified as WUI, the building density must exceed 6.17 buildings per square kilometer. The differentiation between WUI-intermix and WUI-interface is as follows:

1. *WUI-intermix:* An area where at least 50% of the land is covered by wildland vegetation.
2. *WUI-interface:* An area with less than 50% wildland vegetation but located within 2.4 km of a region larger than 5 km².

The toolbox requires some inputs and parameters that user should define. These are three feature layers (i.e. Study Area, Buildings, and Forest Map). Forest map data was obtained from Izmir RFD, and the extent of the study area was extracted from this data. Building data was downloaded in shapefile format from the Geofabrik website, created out of the conviction that free geodata created by projects like OpenStreetMap (https://download.geofabrik.de/europe/turkey.html). Then buildings located within the study area were filtered. All data used as input has the same spatial reference (ED_1950_UTM_Zone_35N). For the present study, cell size was defined as 10 m, and radius was selected as 500 m.

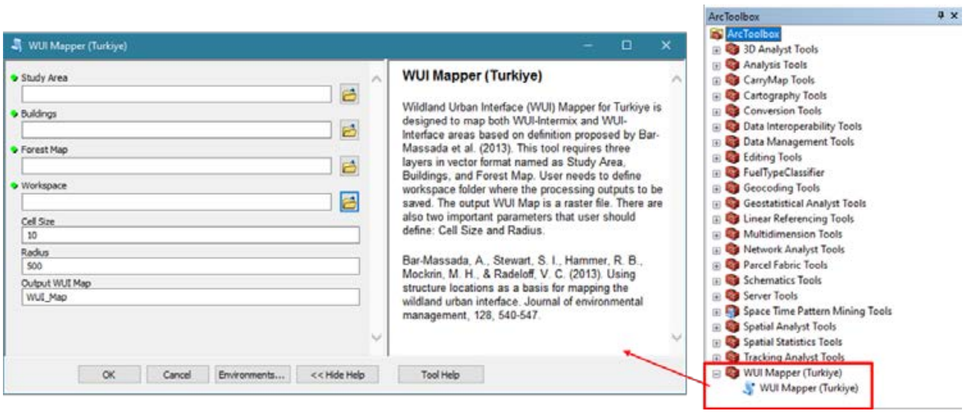



Figure 2. WUI Mapper (Türkiye) toolbox and graphical user interface runs within ArcMap

### 2.3 Forest Fire Susceptibility Mapping

Eker et al. (2024) provided a detailed methodology for mapping forest fire susceptibility. This study utilized raster-based data and applied the Python AutoML framework, PyCaret 3.0, within the Jupyter Notebook environment. In the data preparation step, presence point data for each forest disturbance was gathered, and 15 driving factors were identified based on existing literature. These factors were categorized into topographic, structural, climatic, and forest-related parameters, as follows:

- *Topographic Factors:* Elevation, slope, aspect, and the Topographic Wetness Index (TWI).
- *Structural Factors:* Distance to roads, distance to streams, road density, distance to agricultural areas, and distance to settlements.
- *Climatic Factors:* Total annual precipitation, mean temperature of the warmest quarter, and maximum wind speed.
- *Forest Parameters:* Forest stand types, forest canopy closure, and forest stand development stages.

All driving factors were represented in raster data format with a pixel size of 50 m × 50 m, covering a grid of 5244 rows and 3589 columns. This uniformity in data format ensures consistency throughout the analysis. However, the forest fire susceptibility map resampled with 10 m cell size is shown in Figure 3. According to this map, 88.9% of forested areas within Izmir RFD are susceptible to forest fires, primarily falling into high and very high classes.

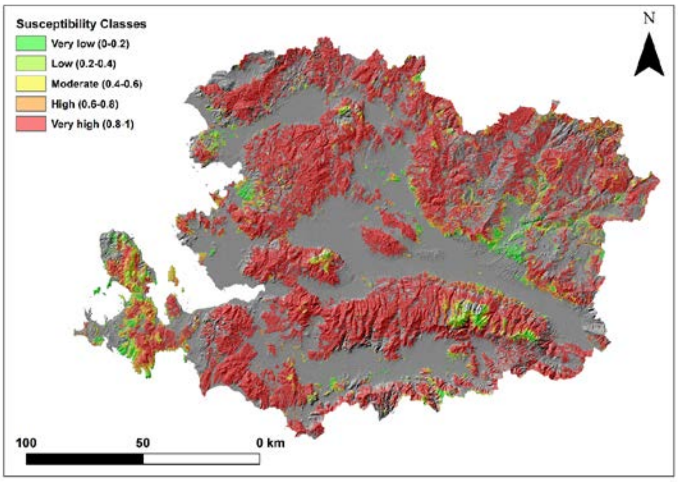



Figure 3. Forest fire susceptibility map created by Eker et al. (2024)

### 2.4 Potential Fire Severity Mapping

The potential fire severity map for the Izmir RFD was generated based on the findings of a study submitted to a scientific journal by Eker and Aydın (2024). The methodology employed by Eker and Aydın (2024) follows a structured approach, as depicted in Figure 4, comprising two main phases:

i) *Creation of Forest Fire Database*: This phase involved compiling a comprehensive forest fire database covering the period from 2018 to 2022. Fire severity was mapped using the dNBR (difference Normalized Burn Ratio) method, which assesses the severity of fire damage based on changes in vegetation indices before and after a fire event.

ii) *Modeling and Predicting Fire Severity*: In this phase, the study focused on modeling and predicting fire severity for various forest types across Türkiye. The RF classification algorithm was utilized for this purpose. Leveraging the capabilities of the GEE platform, the study executed all tasks seamlessly within this integrated environment. A total of 19 features were taken into account for the modeling process. These are Forest Stand Properties as Fuel Types (FMT), Stands Development Stages (SDS), and Canopy Closure (CLS), Elevation (ELEV), Slope (SLP), Aspect (ASP), Topographic Position Index (TPI), Topographic Wetness Index (TWI), Leaf Area Index (LAI), Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Leaf Water Vegetation Index (LWVI), Palmer Drought Severity Index (PDSI), Land Surface Temperature (LST), Maximum Air Temperature (TMAX), Precipitation (PREC), Wind Speed (WSPD), Topographic Diversity Index (TDI), and Fire Density (FDENS).

The potential fire severity map resampled with a 10 m cell size for the Izmir RFD is also given in Figure 5. According to this map, 53.5% of forested areas in Izmir RFD are deemed to have potentially moderate and high fire severity.

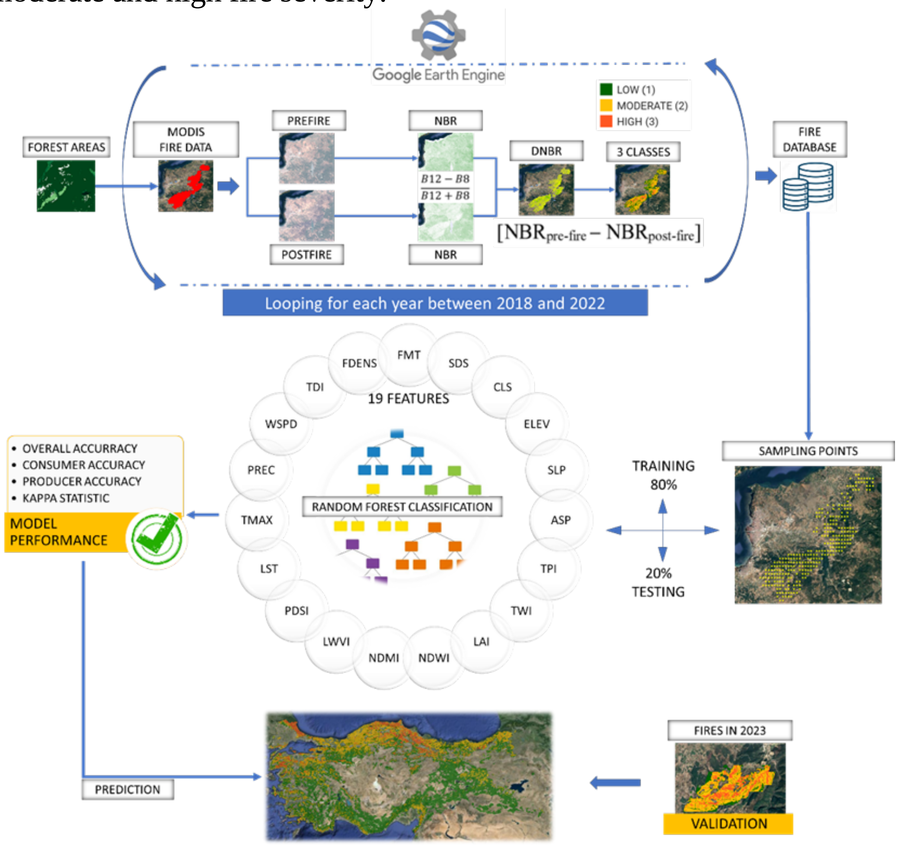


Figure 4. The workflow used in potential fire severity by Eker and Aydın (2024)

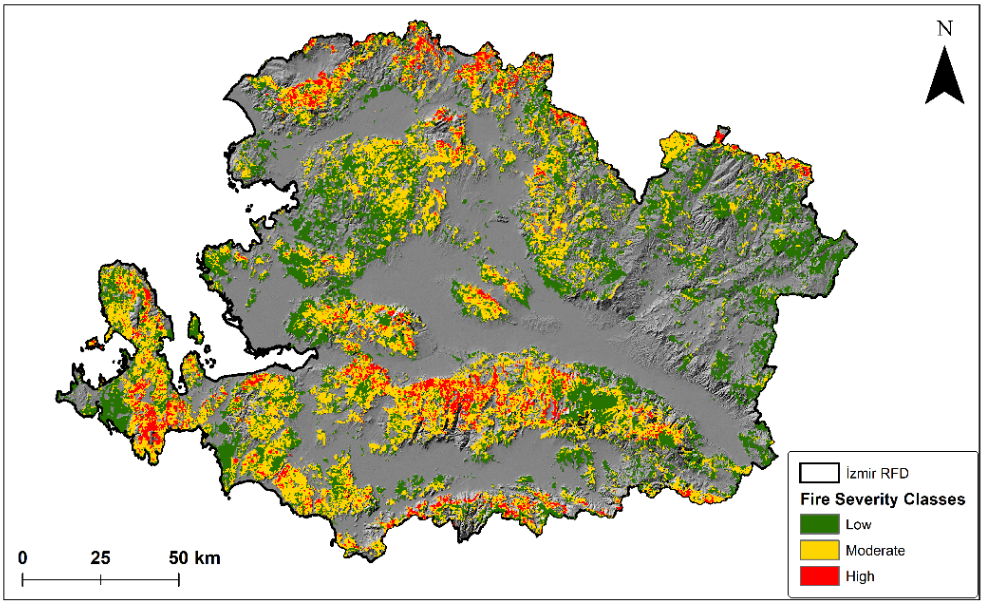



Figure 5. Potential fire severity map for İzmir RFD

**2.5 Assessing forest fire susceptibility and severity within WUI areas**

To assess fire susceptibility and severity within both WUI areas, an overlay analysis was conducted. This analysis involved overlaying the susceptibility and severity maps to determine the number of cells within each class. By quantifying the cells within each class, the area of susceptibility and severity for each class was obtained. This overlay analysis was performed using ArcMap, which allows for the integration and analysis of spatial data. The process involved merging the susceptibility and severity maps and analyzing the resulting layers to calculate the area covered by each class.

## 3. Results and Discussion

The current study presents a methodology for mapping WUI areas, distinguishing between intermix and interface zones, specifically for the İzmir RFD. The WUI mapping criteria are based on the similar guidelines proposed by Bar-Massada et al. (2013), and a script tool was developed to execute this mapping within ArcMap. The generated WUI map is provided in Figure 6. This map delineates the WUI areas, distinguishing between intermix and interface zones, as defined by the methodology proposed in this study. According to the findings, 2.5% of the İzmir RFD is designated as WUI-intermix, while 5.1% is classified as WUI-interface. Following the mapping of both types of WUI areas, an assessment of both fire susceptibility and potential fire severity was conducted within these delineated zones. Tables 1 and 2 present the area percentages of potential fire severity and fire susceptibility classes based on the types of WUI areas, respectively. It was observed that 36.0% of WUI-intermix areas could potentially experience moderate to high severity fires, while 21.7% of WUI-interface areas fell into the potential moderate to high severity classes. Concerning fire susceptibility, 88.6% of WUI-intermix areas were identified as having high to very high susceptibility, while 82.0% of WUI-interface areas exhibited similar susceptibility levels.

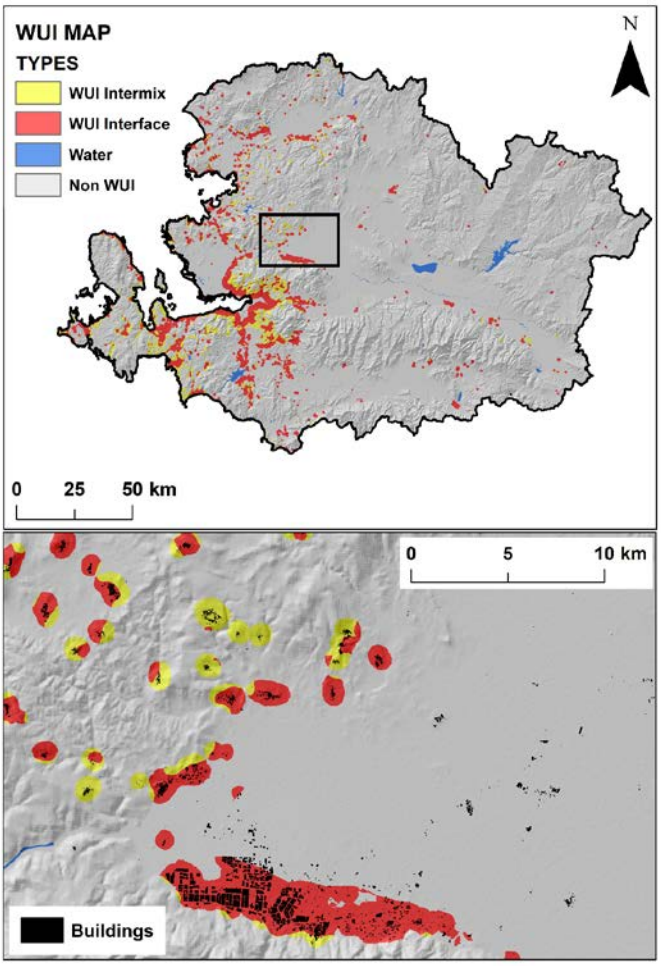



Figure 6. WUI Map of İzmir RFD created with 500 m radius

Table 1. Area (%) of potential fire severity within WUI areas

| | WUI-intermix | | | WUI-interface | | |
|---|---|---|---|---|---|---|
| Fire Severity | Low | Moderate | High | Low | Moderate | High |
| Area (%) | 64.04% | 32.81% | 3.15% | 78.28% | 20.80% | 0.92% |

Table 2. Area (%) of fire susceptibility within WUI areas

| | | | WUI-intermix | | |
|---|---|---|---|---|---|
| Fire Susceptibility | Very low | Low | Moderate | High | Very high |
| Area (%) | 2.94% | 3.94% | 4.54% | 8.68% | 79.90% |
| | | | WUI-interface | | |
| Fire Susceptibility | Very low | Low | Moderate | High | Very high |
| Area (%) | 2.37% | 5.50% | 10.18% | 18.24% | 63.71% |

The WUI mapping methodology applied in this study was based on structure locations, which were obtained as shapefile polygons from OpenStreetMap, representing the latest version available for Türkiye. Bar-Massada et al. (2013) acquired structure locations as points from various sources, including the USDA Forest Service for Huron NF, the U.S. Geological Survey for Grand County, and through digitization for Minong and the Santa Monica Mountains, utilizing Google Maps imagery from 2007 and 2009. Additionally, computer vision algorithms running on high-resolution satellite imagery were employed (Bar-Massada, 2021). The utilization of structure locations primarily hinges on the threshold of building density, which may introduce uncertainties due to limitations in update frequency and the precision of housing and vegetation data (Li et al., 2022). Furthermore, efforts to digitize spatial housing locations or extract them from GPS data could yield errors. However, advancements in remote sensing data quality, including improvements in data acquisition efficiency and spatial resolution, have facilitated the extraction of detailed building footprints. In this study, a radius value of 500 m was selected. Nonetheless, Bar-Massada et al. (2013) investigated its impact by incrementally increasing the radius value in 100 m intervals from 100 m to 1000 m. In this study, after mapping the WUI areas, we proceeded to evaluate both forest fire susceptibility and potential fire severity within these delineated zones. Notably, this study marks the first assessment of potential fire severity within these areas. Understanding the potential severity of forest fires is deemed crucial for informing decisions regarding forest operations. Furthermore, forest susceptibility maps offer valuable insights into areas at high risk of fire, making the evaluation of fire susceptibility within WUI areas exceptionally invaluable.

## 4. Conclusion

In conclusion, this study underscores the critical role of precision forestry methodologies in assessing forest fire susceptibility and potential severity within the WUI of the Izmir RFD in Türkiye. The methodology employed in this study has provided detailed insights into the distribution of WUI zones and their susceptibility to forest fires. Additionally, the application of RF classification on the GEE platform enabled the assessment of potential fire severity within these delineated WUI areas. The findings reveal significant proportions of WUI-intermix and WUI-interface areas exhibiting high susceptibility to forest fires, emphasizing the urgent need for proactive forest management strategies. Moreover, the identification of areas prone to moderate to high fire severity offers valuable information for forest managers to prioritize mitigation efforts and plan effective response strategies. Overall, this research contributes to advancing the field of precision forestry by leveraging cutting-edge technologies and interdisciplinary approaches to enhance forest resilience, protect ecosystems, and safeguard communities living in WUI areas. Moving forward, continued efforts in refining mapping techniques and embracing innovative tools are essential to understand better and mitigate the impact of disturbances like forest fires, ensuring the sustainable management of forest resources and the resilience of forest ecosystems in the face of increasing environmental challenges.

## References

Aksoy, E., Kocer, A., Yilmaz, İ., Akçal, A.N., Akpinar, K. 2023. Assessing Fire Risk in Wildland–Urban Interface Regions Using a Machine Learning Method and GIS data: The Example of Istanbul's European Side. Fire, 6(10): 408.

Akyuz Y.F., Kucukosmanoglu A. 1997. Application of GIS for fire-damaged area in Izmir. Proceedings of the XI World Forestry Congress, Turkey, 13-22 October, Vol. 1

Bar-Massada, A., Stewart, S.I., Hammer, R.B., Mockrin, M.H., Radeloff, V.C. 2013. Using structure locations as a basis for mapping the wildland urban interface. Journal of environmental management, 128: 540-547.

Bar-Massada, A. 2021. A comparative analysis of two major approaches for mapping the wildland-urban interface: A case study in california. Land, 10(7): 679.

Carlson, A.R., Helmers, D.P., Hawbaker, T.J., Mockrin, M.H., Radeloff, V.C. 2022. The wildland–urban interface in the United States based on 125 million building locations. Ecological applications, 32(5): e2597.

Darques, R. 2015. Mediterranean cities under fire. A critical approach to the wildland–urban interface. Applied Geography, 59: 10-21.

Eker, R., Alkiş, K. C., Aydın, A. 2024. Assessment of large-scale multiple forest disturbance susceptibilities with AutoML framework: an Izmir Regional Forest Directorate case. Journal of Forestry Research, 35(1).1-16.

Eker, R., Aydın, A. Predicting potential fire severity in Türkiye's diverse forested areas: a SHAP-integrated random forest classification approach. Stoch Environ Res Risk Assess (2024). https://doi.org/10.1007/s00477-024-02820-1

GDF 2024. Forestry Statistics 2022. https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler. Accessed 13 May 2024

Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A., Lindquist, E. 2015. Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. Forest Ecology and Management, 352:9-20.

Kovacsova, P., Antalova, M. 2010. Precision forestry–definition and technologies. Šumarski list, 134(11-12):603-610.

Kucukosmanoglu A., Uzmez I. 2019. Forest Fires in Izmir Regional Directorate of Forestry. Appl Ecol Environ Res 17(3):6989-7001

Li, S., Dao, V., Kumar, M., Nguyen, P., Banerjee, T. 2022. Mapping the wildland-urban interface in California using remote sensing data. Scientific reports, 12(1):5789.

Modugno, S., Balzter, H., Cole, B., Borrelli, P. 2016. Mapping regional patterns of large forest fires in Wildland–Urban Interface areas in Europe. Journal of environmental management, 172:112-126.

Radeloff, V.C., Hammer, R.B., Stewart, S.I., Fried, J.S., Holcomb, S.S., McKeefry, J.F. 2005. The wildland–urban interface in the United States. Ecological applications, 15(3):799-805.

Sankey, T.T., Tango, L., Tatum, J., Sankey, J.B. 2024. Forest fire, thinning, and flood in wildland-urban interface: UAV and lidar-based estimate of natural disaster impacts. Landscape Ecology, 39(3):58.

Schug, F., Bar-Massada, A., Carlson, A.R., Cox, H., Hawbaker, T.J., Helmers, D., Hostert, P., Kaim, D., Kasraee, N.K., Martinuzzi, S., Mockrin, M.H., Pfoch, K.A., Radeloff, V.C. 2023. The global wildland–urban interface. Nature, 621(7977).94-99.

Taylor, S.E., Veal, M.W., Grift, T.E., McDonald, T.P., Corley, F.W. 2002. Precision forestry: operational tactics for today and tomorrow. In 25th annual Meeting of the council of Forest Engineers (Vol. 6).

# Changes in Topsoil Carbon Stock and Some Hydro Physical Soil Properties and Correlations Among Them After Timber Removal in Broadleaf Mixed Forest

**Reyhan Sağlam*, Ferhat Gökbulak**

Istanbul University-Cerrahpaşa, Faculty of Forestry, Department of Watershed Management, Istanbul, Türkiye
*reyhan.demir@iuc.edu.tr

## Abstract

The objectives of this study were to determine the effects of clearcutting on the organic carbon stock (SOC) and selected hydro-physical soil properties of the topsoil and the correlations between these properties and soil temperature, soil moisture, and herbaceous vegetation. The research was conducted in the oak-hornbeam forest. After clear-cut timber removal from the treatment plots, the topsoil was sampled 3 times a year in both control and treatment plots. The clearcutting decreased SOC, organic matter (SOM), and permeability (HC) of the soil by 62.87%, 72.35%, and 89.12%, respectively, while increased particle density (PD), pH, bulk density (BD), and dispersion ratio (DR) values by 10.91%, 15.15%, 31.30%, and 104.43%, respectively. Results showed that soil temperature was the main factor affecting most of the soil properties Soil temperature had negative correlations with SOC, SOM, EC, field capacity (FC), permanent wilting point (PWP), available water capacity (AWC), HC, saturation capacity (SC), and total porosity (TP) and positive correlations with pH, BD, PD, and DR properties of the soil ($p<0.05$). Soil moisture had positive correlations with AWC and DR and negative correlations with HC and TP. Vegetation cover had a positive correlation with pH and a negative correlation with SC.

***Keywords:*** *Soil organic carbon, timber removal, vegetation cover, microclimate*

## 1. Introduction

Forests provide many important ecosystem services, including timber production, watershed regulation, erosion control, and wildlife habitat (Erdoğan, 2020). In this sense, forests, which are of great importance, play a role in mitigating climate change due to their capacity to fix $CO_2$ in the atmosphere (Pan et al., 2011; Jackson et al., 2017; Yu et al., 2022). Both trees and soils have a carbon storage function for forest ecosystems. Carbon cycles in forests occur in living biomass, litter, and soil. There are different results for the amount of carbon sequestered in the soil globally. For example, it was reported that more than 40% of the carbon in terrestrial ecosystems is stored in forest soils (IPCC, 2007). The study by Scharleman et al., (2014) suggested that the amount of organic carbon in soil is around 1500 Pg C (billion tons of carbon) globally. As a general ratio, it can be said that the carbon in the soil is 2/3 of the total soil carbon (Serengil, 2020). The remaining amount is inorganic carbon. Soil organic carbon is one of the major components of soil organic matter (SOM), which plays an important role in many biological, chemical, and physical properties of soil (James and Harrison, 2016). Soil organic matter consists of plant parts accumulating on the ground and establishing the forest floor.

A good understanding of soil carbon and changes in carbon stocks can enable the development of better management strategies (Serengil, 2020). Both anthropogenic effects such as land conversion and fire, and forestry practices such as forest harvesting and thinning can cause losses in soil organic carbon (Wäldchen et al., 2013; Kim et al., 2021). Carbon stock levels vary significantly depending on climate, soil properties, land use, species composition, and management practices. For example, compaction of soils, removal of leaves from the area (e.g. recreation), changing the stand structure, the processes of litter accumulation and its decomposition, and similar practices have the potential to change the carbon stock in the soil (Crow et al., 2007; Wäldchen et al., 2013; Cheng et al., 2017). In agricultural and rangelands, frequent tilling, fertilization, preference for annual plants, and overgrazing grazing are known to have negative effects on organic matter and carbon stock (Serengil, 2020). In addition, forest ecosystems are cut for silvicultural techniques such as timber production and forest tending, and for protection against environmental effects such as fire and drought resistance (Rab, 2004; Wäldchen et al., 2013). Therefore, forest harvesting is an important forestry practice widely used in forest management. However, harvesting practices change many environmental elements such as microclimate, soil microorganism activities, energy reaching the soil, wind speed, soil temperature, and moisture depending on the intensity of the cutting. With clearcutting, the vegetation cover is completely removed, which causes the soil to receive more solar radiation during the day and to lose more long-wave radiation at night (Renaud and Rebetez, 2009; Garduño et al., 2010; Foote et al., 2015; Sağlam and Gökbulak, 2024). In this case, in addition to diurnal variations in soil temperature, soil microorganism activities and decomposition rates also increase (Zheng et al., 2000; Cheng et al., 2017). Therefore, clearcutting causes a decrease in soil carbon stocks and dynamics both directly and indirectly (Nave et al., 2010; Busman et al., 2021; Zanvo et al., 2023). Some studies have shown that cutting deteriorates soil properties, including increased soil bulk density and decreased soil water holding capacity and porosity (Rab, 2004; Zhou et al., 2015; Muscolo et al., 2021).

In this study, we aimed to investigate the effects of clearcutting on soil organic carbon stock and selected hydrophysical soil properties of topsoil. We also examined the impact of soil temperature, soil moisture, and herbaceous vegetation on soil organic carbon stock.

## 2. Material and Methods

### 2.1 Study Area

The study was conducted in the Research Forest of Istanbul University-Cerrahpaşa, Faculty of Forestry. The research site is located between 28° 59' 17'' - 29° 32' 25'' E longitudes and 41° 09' 15'' - 41° 11' 01'' N latitudes with an altitude ranging from 20 m to 236 m above the sea level.

In this area, powerlines pass through some areas, cleared by timber harvesting at certain intervals by the Electricity Administration. Clearcutting was carried out in the study area as of June 2019. Within the scope of this study, three clear-cut areas and three oak-hornbeam coppice forests located within the boundaries of the Research Forest of Istanbul University-Cerrahpaşa, Faculty of Forestry were determined as sampling points (Figure 1). The study area's bedrock is clay schists, the soil group is Luvisol, and the clay loam is usually in texture (IUSS Working Group WRB, 2006).

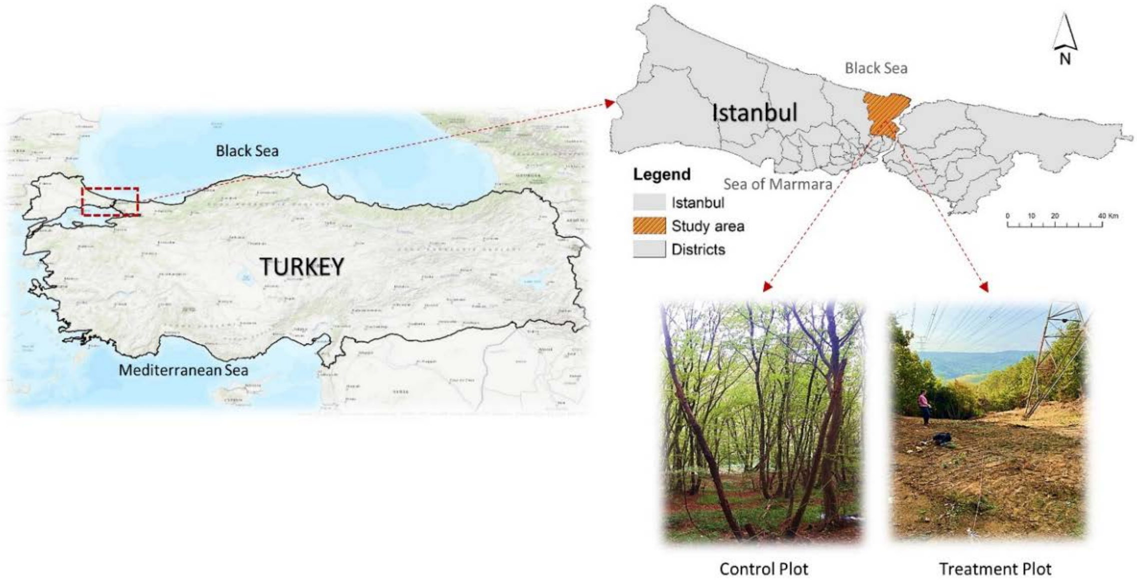



Figure 1. Location of the study area

The study area's annual average temperature and precipitation are 12.8 °C and 1111.4 mm, respectively. According to the Thornthwaite climate classification method, the climate type was determined as humid, mesothermal, with a moderate water deficit in summer and close to oceanic climate conditions (climate type $B_3B_1$'$sb_1$') (Demir, 2021). Meteorological data were obtained from the meteorological station (117 m altitude) located in Bahçeköy, 1.5 km from the experimental area. The dominant tree species in the field are *Quercus petrea ssp. iberica, Quercus cerris var. austriaca, Quercus robur, Quercus frainetto*. Other tree species constituting the forest formation include *Castanea sativa*, *Tilia tomentosa*, *Carpinus betulus*, and *Corylus avellana* species, forming mixed stands (Ayaşlıgil, 1997).

**2.2 Experimental Design and Sampling Procedure**

In this study, the areas where the clearcutting performed were defined as the treatment plot and untouched oak-hornbeam forest areas immediately adjacent to it were chosen as the control plot. Three sampling areas with similar characteristics were selected for the control and treatment plots, and measurements and observations were made at these points. Soil samples were taken from 10 randomly determined points in each plot. Soil samples were taken in three periods after cutting: October 2019, May 2020, and October 2020. Since the effect of the clearcutting on the soil is primarily on the surface soil, only the topsoil samples at a depth of 0-10 cm were collected to understand the short-term effect. Steel cylinders with a volume of 326 $cm^3$, sharp on one side and with numbers on it, were used to collect soil samples whose natural structure was not disturbed. A total of 180 samples were taken from the treatment and control plots for this study. Air-dried soil samples were sieved through a 2 mm mesh to prepare soil samples for analysis. Soil samples were analyzed for the following properties: SOC (Mg $ha^{-1}$), SOM (%), BD ($g/cm^{-3}$), DR, PD (g $cm^{-3}$), TP (%), pH, EC (μS $cm^{-1}$), SC (%), HC (mm $h^{-1}$), FC (%), PWP (%), and AWC (%).

Soil temperature and soil moisture measurements were measured weekly between the years 2020 and 2021. Soil temperature was measured at ten fixed points determined at each sampling site. Temperature measurements were made weekly in the field at 10 cm soil depth using digital thermometers. In the measurement of soil moisture, gypsum blocks covered with plastic resin, which can easily trap moisture due to its porous structure, were used and measured with the Bouyoucos BN-2B model moisture meter. Soil moisture was measured at 50 cm soil depth.

Vegetation observations were made on three permanent transect lines randomly placed in each plot during the vegetation period (March-October) between the years 2020 and 2021. In each of the treatment and control plots, three permanent transect lines of 10 m in length were created to represent the sampling areas. Vegetation measurements were made along the transect line using a 0.5 x 0.5 m quadrat placed randomly left or right side of the line with 2 m intervals. Parameters defining vegetation characteristics were recorded by observing and counting plants on transect lines during the 8-month vegetation period. Vegetation cover refers to the "vegetated area" in terms of the degree of vegetation cover of the plant species (Gökbulak, 2013). The quadrate method was used to determine the vegetation cover. The percentage of the plant-covered area in the 0.25 $m^2$ quadrate was visually estimated and recorded.

**2.3 Laboratory Analysis**

PD was measured using the pycnometer method. BD was measured by dividing the mass of the soil core content by the core volume. TP was calculated according to the relationship between the soil particle density and the soil bulk density (Özhan, 2004). Soil pH and EC were determined in a solution composed of 1:5 soil:water mixture using a WTW Multiline P4 Universal Meter (WTW, Weilheim, Germany). SOM content was determined by the Walkley Black wet digestion method (Gülçur, 1974). HC was measured according to Darcy's law equation (Özhan, 2004). FC was determined as the moisture content of the samples under 1/3 atm pressure and PWP was found as moisture content of the samples under 15 atm pressure. AWC was estimated as the difference between the moisture percentages between field capacity and permanent wilting point (Huntington, 2007).

**2.4 Data Analysis**

The experiment was a completely randomized two-factor (land use, period) design with 3 replications (Zar, 1996). The soil carbon fraction determined from the laboratory was used to estimate the carbon stock in the soil by applying the following Equation 1:

$$\text{SOC (Mg ha}^{-1}) = \text{OC} \times \text{LT} \times \text{BD} \times (1 - \text{RF}) \times 10^4 \quad (1)$$

Where OC is the organic carbon concentration (%), LT is the layer thickness (m), BD is the topsoil bulk density (Mg $m^{-3}$), and RF is the correction factor for stoniness (Serengil, 2020).
To evaluate the effect of cutting on soil properties, we calculated the relative change between soil physical values in the treatment and control area using Equation 2:

$$\text{Relative Changes (\%)} = \frac{\text{Soil parameters in the treatment plot}}{\text{Soil parameters in the control plot}} \times 100\text{-}100 \quad (2)$$

One-way ANOVA was used to compare study sites with different forest management. The means of factors showing significant differences were compared with the Tukey test ($p<0.05$). Jamovi 2.4.11 and Microsoft Office Excel 2016 programs were used for statistical analysis of the study data. Before applying variance analysis to the data, a normality test was performed on data and if needed, necessary transformations were made for data that did not show normal distribution.

The relationship between soil temperature, soil moisture, and vegetation cover with soil physical and chemical properties was tested using Pearson correlation. The effects were considered to be significantly different at an alpha level of 0.05 ($p<0.05$).

## 3. Results and Discussion

### 3.1 Soil Physical and Chemical Properties

Clearcutting affected all soil properties including SOC, DR, PH, EC, SOM, HC, SC, BD, PD, TP, FC, PWP, and AWC ($p<0.05$). SOC content in the treatment plot decreased significantly ($p<0.05$) compared to the control plot. In general, no recovery was observed in soil properties in the one-year after clearcutting ($p<0.05$) (Table 1). A worldwide meta-analysis of forest harvesting studies by Nave et al., 2010 found that harvesting reduces soil carbon. In their study, mineral soil carbon decreased over time after harvest but recovered 6–20 years after harvest. Cheng et al. (2017) reported that thinning had no significant effect on total SOC concentrations in the 0–60 cm soil layers after 15 years of application. Another study suggested that soil carbon stocks were not affected by harvesting intensity and increased with an increase in soil depth (Zanvo et al., 2023).

According to our study findings, HC decreased significantly after cutting (mean 89% decrease) ($p<0.05$). The mean BD and PD were significantly higher in the treatment plot due to soil compaction. This change seems to affect compaction from machine traffic (Sağlam and Gökbulak, 2024). Goutal et al. (2012) observed a 6% (30-40 cm soil depth) and 27% (0-10 cm soil depth) increase in BD after forwarder traffic, while Jankovský et al. (2019) reported an increase in BD ranging from 35% to 38% after machine traffic. Soil porosity decreases in soils with increased BD, resulting in lower saturation capacity values (Busman et al., 2021). Our study findings also coincided with this. TP and SC values decreased by 20% and 37% in the treatment plot compared to the control plot. DR was the soil parameter most affected by cutting and showed a significant increase of 104% ($p<0.05$) (Table 1).

In this study, SOM content decreased by 72% compared to the control plot, from 4.10% to 1.49% ($P<0.05$). Similarly, Zhou et al. (2015) also reported that due to harvesting, there was a 44% decrease in the organic matter content of the soils compared to the forest area. After the treatment soils' all FC, PWP, and AWC values significantly decreased ($P<0.05$, Table 1) and did not recover over the 1 year. Because of their higher organic matter content, soils in control plots in the forested area had higher FC, PWP, and AWC than those in treatment plots in the clearcut area.

Clearcutting caused changes in soil temperature, soil moisture, and vegetation cover (Table 2). While the average soil temperature in the control plot was 15.3 °C, the average soil temperature in the treatment plot was 17.4 °C. Zhang et al. (2018) monitored the changes in soil temperature and soil moisture according to the intensity of silvicultural application (light, moderate, and heavy). It was emphasized that soil temperature increased by 7.8%, 5.6%, and 16.1%, respectively, due to the reduction of the tree canopy. On the other hand, clearcutting caused a significant decrease in soil moisture by approximately 1% in our study ($p<0.05$).

Table 1. Mean values (Mean ± SD) of physical and chemical soil parameters in three different periods under control and treatment plots

| Soil parameters | Land Use | Year | | |
|---|---|---|---|---|
| | | October 2019 | May 2020 | October 2020 |
| Soil organic carbon (Mg ha$^{-1}$) | Control | 86.52$^{a*}$ ± 21.43 | 81.08$^{a}$ ± 32.92 | 107.42$^{a}$ ± 32.11 |
| | Treatment | 29.49$^{b}$ ± 26.93 | 31.10$^{b}$ ± 25.51 | 41.51$^{b}$ ± 26.41 |
| Dispersion ratio | Control | 19.6$^{a*}$ ± 7.05 | 35.5$^{a}$ ± 9.19 | 24.1$^{a}$ ± 6.12 |
| | Treatment | 48.5$^{b}$ ± 12.00 | 61.13$^{b}$ ± 11.09 | 52.3$^{b}$ ± 11.10 |
| pH | Control | 4.92$^{a*}$ ± 0.24 | 4.88$^{a}$ ± 0.24 | 5.65$^{a}$ ± 0.41 |
| | Treatment | 5.70$^{b}$ ±0.55 | 5.77$^{b}$ ± 0.59 | 6.33$^{b}$ ± 0.52 |
| Electrical conductivity (µS cm$^{-1}$) | Control | 71.8$^{a*}$ ± 14.4 | 83.4$^{a}$ ± 17.9 | 86.1$^{a}$ ± 21.9 |
| | Treatment | 60.1$^{b}$ ± 25.1 | 63.6$^{b}$ ± 26.9 | 53.4$^{b}$ ± 15.8 |
| Soil organic matter (%) | Control | 4.10$^{a*}$ ± 1.15 | 3.57$^{a}$ ± 1.34 | 5.34$^{b}$ ± 1.51 |
| | Treatment | 1.08$^{c}$ ± 0.95 | 1.11$^{c}$ ± 0.93 | 1.49$^{c}$ ± 0.94 |
| Hydraulic conductivity (mm h$^{-1}$) | Control | 752.2$^{a*}$ ± 902.3 | 950.7$^{a}$ ± 1287.6 | 1105.6$^{a}$ ± 1802.3 |
| | Treatment | 79.6$^{b}$ ± 93.8 | 107.0$^{b}$ ± 142.4 | 118.8$^{b}$ ± 209.4 |
| Saturation capacity (%) | Control | 48.3$^{a*}$ ± 7.01 | 48.5$^{a}$ ± 7.81 | 46.0$^{a}$ ± 6.42 |
| | Treatment | 31.7$^{b}$ ± 5.02 | 30.9$^{b}$ ± 6.76 | 27.0$^{b}$ ± 2.72 |
| Bulk density (g cm$^{-3}$) | Control | 1.18$^{a*}$ ± 0.13 | 1.20$^{a}$ ± 0.13 | 1.08$^{a}$ ± 0.12 |
| | Treatment | 1.50$^{b}$ ± 0.16 | 1.55$^{b}$ ± 0.10 | 1.49$^{b}$ ± 0.15 |
| Particle density (g cm$^{-3}$) | Control | 2.25$^{a*}$ ± 0.07 | 2.23$^{a}$ ± 0.08 | 2.13$^{b}$ ± 0.10 |
| | Treatment | 2.44$^{c}$ ± 0.05 | 2.42$^{c}$ ± 0.06 | 2.45$^{c}$ ± 0.11 |
| Total porosity (%) | Control | 47.6$^{a*}$ ± 5.75 | 46.2$^{a}$ ± 6.14 | 49.3$^{a}$ ± 6.33 |
| | Treatment | 38.5$^{b}$ ± 7.33 | 36.0$^{b}$ ± 3.97 | 39.2$^{b}$ ± 6.11 |
| Field capacity (%) | Control | 30.1$^{a*}$ ± 3.84 | 34.4$^{b}$ ± 3.50 | 33.6$^{b}$ ± 2.77 |
| | Treatment | 22.5$^{c}$ ± 3.03 | 23.2$^{c}$ ± 2.89 | 22.3$^{c}$ ± 1.87 |
| Permanent wilting point (%) | Control | 17.7$^{a*}$ ± 3.73 | 19.4$^{a}$ ± 3.37 | 20.9$^{ba}$ ± 5.23 |
| | Treatment | 13.5$^{c}$ ± 3.44 | 11.5$^{c}$ ± 3.97 | 12.1$^{c}$ ± 2.80 |
| Available water capacity (%) | Control | 12.4$^{a*}$ ± 2.86 | 15.0$^{a}$ ± 2.02 | 12.7$^{a}$ ± 3.23 |
| | Treatment | 9.0$^{b}$ ± 1.92 | 11.7$^{b}$ ± 2.55 | 10.2$^{b}$ ± 3.50 |

*Means that different superscript letters are significantly different among years in the same row and between land uses for the same soil characteristic in the same year (P<0.05).

Table 2. Mean values (mean ± SD) of environmental variables for treatment and control plots

| Environmental variables | Treatment plot | Control plot |
|---|---|---|
| Soil temperature ($^{0}$C) | 17.40$^{a*}$ ± 2.98 | 15.30$^{b}$ ± 1.33 |
| Soil moisture (%) | 35.26$^{a*}$ ± 5.71 | 36.33$^{b}$ ± 6.41 |
| Vegetation cover (%) | 22.20$^{a*}$ ± 4.86 | 13.40$^{b}$ ± 2.50 |

*Means with different superscript letters are significantly different at the same row (P<0.05)

Sunlight directly reaches the bare soil surface and increases evaporation, reducing the soil's moisture capacity. Miah et al. (2014) stated in their study that clear-cutting caused a decrease in soil moisture due to evaporation. In this respect, it is similar to the findings in our study. After clearcutting, the herbaceous vegetation cover in the area was monitored. While the vegetation cover was found to be 22.20% in the treatment plot, it was found to be 13.40% in the control plot. In general, Rubus sp. (43.38%) had the highest share in the treatment plot, while Hedera helix L. (20.89%) was in the control plot. The fact that the clearcutting effect increased light uptake was supported by studies showing an increase in the vegetation cover values of the species in the clear-cut area (Krzic et al., 2003; Dimov et al., 2015).

### 3.1 Correlation between Environmental Variables and Soil Properties

Soil temperature was positively correlated with dispersion rate, pH, bulk density, and particle density and negatively correlated with soil organic carbon, electrical conductivity, soil organic matter, hydraulic conductivity, saturation capacity, total porosity, field capacity, permanent wilting point, and available water capacity. Soil moisture was positively correlated with dispersion rate, and available water capacity but negatively correlated with hydraulic conductivity and total porosity. Vegetation cover was positively correlated with pH and negatively correlated with saturation capacity, while vegetation cover had no significant correlation with other parameters (Table 3).

Table 3. Correlation between environmental variables and soil properties

| Soil Parameters | Environmental variables | | |
|---|---|---|---|
| | ST | SM | VC |
| SOC | -0.349** | 0.043 | 0.038 |
| DR | 0.383** | 0.179* | 0.098 |
| pH | 0.464** | 0.041 | 0.243** |
| EC | -0.284** | 0.044 | 0.063 |
| SOM | -0.368** | -0.009 | -0.003 |
| HC | -0.269** | -0.188* | -0.065 |
| SC | -0.629** | 0.004 | -0.167* |
| BD | 0.463** | 0.146 | 0.043 |
| PD | 0.482** | 0.038 | 0.078 |
| TP | -0.355** | -0.167* | -0.022 |
| FC | -0.588** | -0.019 | 0.021 |
| PWP | -0.430** | -0.127 | 0.009 |
| AWC | -0.395** | 0.184* | -0.001 |

* Significant correlation at 0.05 level; ** Significant correlation at 0.01 level. SOC—soil organic carbon, DR—dispersion ratio, EC—Electrical conductivity, SOM—soil organic matter, HC—hydraulic conductivity, SC—saturation capacity, BD—bulk density, PD—particle density, TP—total porosity, FC—field capacity, PWP—permanent wilting point, AWC—available water capacity, ST—soil temperature, SM—soil moisture, VC—vegetation cover

## 4. Conclusion and Suggestions

In this study, we found that clearcutting significantly affected soil organic carbon and other hydrophysical soil properties. Approximately 63% of the SOC stock in the field was removed from the field with clearcutting. After clearcutting, bulk density and particle density in the treatment plot increased significantly compared to the control plot. This caused a decrease in soil porosity and saturation capacity. This is closely related to the decrease in soil permeability, infiltration capacity, and saturation capacity of the soil. On the other hand, the removal of vegetation and residues from the field caused SOM reductions. Again, removing aboveground biomass from the field decreased the field capacity and caused decreases in AWC available for plant growth. There was no recovery in soil properties over 1 year. In addition, clearcutting changed the microclimate, surface energy balance, and activities of the soil microbial community. After clearcutting, soil temperature increased by 2.1 °C, and soil moisture decreased. Removal of forest cover increases daily changes in soil temperature, which accelerates microbial activities and the decomposition of litter. Therefore, clearcutting affects soil carbon stocks and dynamics both directly and indirectly.

A trend towards nature-oriented forestry and continuous cover forestry will reduce the importance of clearcutting. Thus, clearcutting with a structure close to forest ecosystems will affect both microclimate and soil C content and moisture content. On the other hand, differences or changes in harvesting technologies will also affect the result. Instead of machinery that causes soil compaction, such as bulldozers, machinery such as tractors or sleds can be preferred. In addition, guidelines regarding minimizing soil damage and erosion by forest machinery, for example, will generally support the preservation of SOC. Harvest residues can be distributed in the clearcut area after felling. Harvest residues can be placed on the paths where harvesters drive to reduce their impact on the soil. Especially thin branches and leaves, where the nutrients of the trees are collected in large quantities, will be left on the field, both preserving the soil and having a positive effect in terms of nutrients.

**References**

Ayaşlıgil, T. 1997. İ.Ü. Orman Fakültesi Eğitim ve Araştırma Ormanının rekreasyonel potansiyelinin saptanması (Evaluation of recreational potential of the Research Forest of Faculty of Forestry, Unıversity of Istanbul). Journal of the Faculty of Forestry Istanbul University. 47(2): 175-200. https://dergipark.org.tr/tr/pub/jffiu/issue/18851/198986

Busman, N.A., Maie, N., Ishak, C.F., Sulaiman, M.F., Melling, L. 2021. Effect of compaction on soil CO2 and CH4 fluxes from tropical peatland in Sarawak, Malaysia. Environmental Development and Sustainability. 23(2): 1–14. https://doi.org/10.1007/s10668-020-01132-y

Cheng, X., Yu, M., Wang, G.G. 2017. Effects of thinning on soil organic carbon fractions and soil properties in Cunninghamia lanceolata stands in eastern China. Forests. 8(6): 1–14. https://doi.org/10.3390/f8060198

Crow, S.E., Swanston, C.W., Lajtha, K., Brooks, J.R., Keirstead, H. 2007. Density fractionation of forest soils: Methodological questions and interpretation of incubation results and turnover time in an ecosystem context. Biogeochemistry. 85(1): 69–90. https://doi.org/10.1007/s10533-007-9100-8

Demir, R. 2021. Baltalık işletmesinde traşlama kesiminin üst toprağın bazı hidro-fiziksel özellikleri ve otsu vejetasyon üzerindeki etkisi (Effect of coppice forest clearance on some hydrophysical soil properties and herbaceous vegetation on topsoil). Master thesis, Istanbul University-Cerrahpasa, Institute of Graduate Studies, Istanbul, Turkey.

Dimov, L.D., Howard, K.J., Leggett, Z.H., Sucre, E.B., Weninegar, L.L. 2015. Removal of organic matter from the forest floor in loblolly pine plantations increased ground-layer richness and diversity 16 years after treatment. Forest Science. 61(3): 554– 558. https://doi.org/10.5849/forsci.13-151

Erdoğan, B.U. 2020. Evaluation of ecosystem services concept at watershed scale and its integration into planning. Düzce University Faculty of Forestry Journal of Forestry. 16(2): 196–216. https://dergipark.org.tr/tr/download/article-file/1431123

Foote, J.A., Boutton, T.W., Scott, D. A. 2015. Soil C and N storage and microbial biomass in US southern pine forests: Influence of forest management. Forest Ecology and Management. 355: 48-57. https://doi.org/10.1016/j.foreco.2015.03.036

Garduño, H.R., Fernald, A.G., Cibils, A.F., VanLeeuwen, D.M. 2010. Response of understory vegetation and soil moisture to infrequent heavy defoliation of chemically thinned juniper woodland. Journal of Arid Environments. 74(2): 291–297. https://doi.org/10.1016/j.jaridenv.2009.08.005

Goutal, N., Boivin, P., Ranger, J. 2012. Assessment of the natural recovery rate of soil specific volume following forest soil compaction. Soil Science Society of America Journal. 76(4): 1426–1435. https://doi.org/10.2136/sssaj2011.0402

Gökbulak, F. 2013. Meralarda vejetasyon analizi. Istanbul University Publication No.: 5151, Faculty of 527 Forestry (Publication Number: 503 (In Turkish)), Yazın Press Publishing, Istanbul.

Huntington, T.G. 2007. Available water capacity and soil organic matter. In Encyclopedia of Soil Science. 2nd ed., pp. 139-143. Taylor and Francis: New York. https://doi.org/10.1201/9780429445552-36

IPCC. 2007. Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, UK and New York.

IUSS Working Group WRB. 2006. World reference base for soil resources 2006. International soil classifcation system for naming soils and creating legends for soil maps. World soil resources reports no. 103. FAO, Rome.

Jackson, R.B., Lajtha, K., Crow, S.E., Hugelius, G., Kramer, M.G., Pineiro, ˜ G. 2017. The ecology of soil carbon: pools, vulnerabilities, and biotic and abiotic controls. Annual Review of Ecology, Evolution, and Systematics. 48: 419–445. https://doi.org/10.1146/annurev-ecolsys-112414- 054234

James, J., Harrison, R. 2016. The effect of harvest on forest soil carbon: A meta-analysis. Forests, 7(12). https://doi.org/10.3390/f7120308

Jankovský, M., Allman, M., Allmanová, Z., Ferenčík, M., Vlckova, M. 2019. Changes of key soil parameters five years after forest harvesting suggest slow regeneration of disturbed soil. Journal of Sustainable Forestry. 38(4): 369–380. https://doi.org/10.1080/10549811.2018.1549500

Kim, I., Han, S.K., Acuna, M., Woo, H., Oh, J.H., Choi, B. 2021. Effect of heavy machine traffic on soil Co2 concentration and efflux in a pinus koraiensis thinning stand. Forests. 12(11): 1–15. https://doi.org/10.3390/f12111497

Krzic, M., Newman, R.F., Broersma, K. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of Northeastern British Columbia. Forest Ecology and Management. 182(1-3): 315-325. https://doi.org/10.1016/S0378-1127(03)00064-1

Gülçur, F. 1974. Toprağın fiziksel ve kimyasal analiz metodları. Istanbul University Publication No.: 1970, Faculty of Forestry (Publication Number: 201 (In Turkish)), Kutulmuş Press Publishing, Istanbul.

Miah, S., Habiba, U., Sirajul Haque, S.M., Shumi, W., Abdu, A., Shukor, N.A.A., Hossain, M.A. 2014. Effects of deforestation on physicochemical properties and microbial population of soils in a South-East Asian tropical forest. Journal of Food. Agriculture and Environment. 12(2): 986-991.

Muscolo, A., Settineri, G., Romeo, F., Mallamaci, C. 2021. Soil biodiversity as affected by different thinning intensities in a Pinus laricio stand of calabrian apennine, south Italy. Forests. 12(1): 1-15. https://doi.org/10.3390/f12010108

Nave, L.E., Vance, E.D., Swanston, C.W., Curtis, P.S. 2010. Harvest impacts on soil carbon storage in temperate forests. Forest. Ecology. Management. 259(5): 857–866. https://doi.org/10.1016/j.foreco.2009.12.009

Özhan, S. 2004. Havza Amenajmanı. Istanbul University Publication No.: 4510, Faculty of Forestry (Publication Number: 481), Istanbul.

Pan, Y.D., Birdsey, R.A., Fang, J.Y., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, A.D., Piao, S.L., Rautiainen, A., Sitch, S., Hayes, D. 2011. A large and persistent carbon sink in the world's forests. Science. 333: 988–993. https://doi.org/10.1126/science.1201609

Rab, A. 2004. Recovery of soil physical properties from compaction and soil profile disturbance caused by logging of native forest in Victorian Central Highlands, Australia. Forest Ecology and Management. 191(1): 329–340. https://doi.org/10.1016/j.foreco.2003.12.010

Renaud, V., Rebetez, M. 2009. Comparison between open-site and below-canopy climatic conditions in Switzerland during the exceptionally hot summer of 2003. Agricultural and Forest Meteorology. 149(5): 873–880. https://doi.org/10.1016/j.agrformet.2008.11.006

Sağlam, R., Gökbulak, F. 2024. Effect of frequent clearcutting on some soil properties, temperatures, and herbaceous vegetation and the potential of their recovery in a short time. Environmental Monitoring and Assessment, 196(9): 1-14. https://doi.org/10.1007/s10661-024-13044-9

Serengil, Y. 2020. Climate Change and Carbon Management, United Nations Development Program Report.

Six, J., Paustian, K. 2014. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. Soil Biology and Biochemistry. 68: A4–A9. https://doi.org/10.1016/j.soilbio.2013.06.014

Scharlemann, J.P.W., Tanner, E.V.J., Hiederer, R., Kapos, V. 2014. Global soil carbon: Understanding and managing the largest terrestrial carbon pool. Carbon Management. 5(1): 81–91. https://doi.org/10.4155/cmt.13.77

Wäldchen, J., Schulze, E.D., Schöning, I., Schrumpf, M., Sierra, C. 2013. The influence of changes in forest management over the past 200 years on present soil organic carbon stocks. Forest Ecology and Management. 289:243–254. https://doi.org/10.1016/j.foreco.2012.10.014

Yu, Z., Ciais, P., Piao, S.L., Houghton, R.A., Lu, C.Q., Tian, H.Q., Agathokleous, E., Kattel, G., Sitch, S., Goll, D.S., Yue, X., Walker, A.P., Friedlingstein, P., Jain, A.K., Liu, S.R., Zhou, G.Y. 2022. Forest expansion dominates China's land carbon sink since 1980. Nature Communications. 13(1): 1–12. https://doi.org/10.1038/s41467-022- 32961-2

Zanvo, S.M.G., Salako, K.V., Mensah, S., Glèlè Kakaï, R. 2023. Impacts of harvesting intensity on carbon allocation to species, size classes and pools in mangrove forests, and the relationships with stand structural attributes. Ecological Indicators. 155. https://doi.org/10.1016/j.ecolind.2023.111037

Zar, J.H. 1996. Biostatistical Analysis. 3rd ed. Prentice Hall, Upper Saddle River, NJ.

Zhang, X., Guan, D., Li, W., Sun, D., Jin, C., Yuan, F., Wang, A., Wu, J. 2018. The effects of forest thinning on soil carbon stocks and dynamics: A meta-analysis. Forest Ecology and Management. 429(2018): 36–43. https://doi.org/10.1016/j.foreco.2018.06.027

Zheng, D., Chen, J., Song, B., Xu, M., Sneed, P., Jensen, R. 2000. Effects of silvicultural treatments on summer forest microclimate in southeastern Missouri Ozarks. Climate Research. 15(1): 45-59. https://doi.org/10.3354/cr015045

Zhou, X., Zhou, Y., Zhou, C., Wu, Z., Zheng, L., Hu, X., Chen, H. Gan, J. 2015. Effects of cutting intensity on soil physical and chemical properties in a mixed natural forest in southeastern China. Forests. 6(12): 638 4495-4509. https://doi.org/10.3390/f6124383

# How to Save Timber Products from Wildfires by Improving Forest Road Standards?

**Abdullah E. Akay[1], Neşat Erkan[1], Ebru Bilici[2], Zennure Uçar[3], C. Okan Güney[4]**

[1]Bursa Technical University, Faculty of Forestry, Department of Forest Engineering, Bursa, Türkiye
[2]Giresun University, Dereli Vocational School, 28902 Giresun, Türkiye
[3]İzmir Katip Çelebi University, Faculty of Forestry, Department of Forest Engineering, 35620 İzmir, Türkiye
[4]Aegean Forestry Research Institute, Department of Forest Fires, İzmir, Türkiye
*abdullah.aka@btu.edu.tr

---

## Abstract

Forest fires affect the system elements that form the forest ecosystem, resulting in economic, ecological, and social impacts. In this regard, following factors can be considered: the extinguishing efforts carried out during the fire and the resources spent for this purpose, the assets in the forest that are affected by the fire and constitute economic value, the decrease in the benefits of the forest for people living in or adjacent to the forest, and the decrease in the environmental values produced by the forests and which have economic equivalents. A scientific study assessing the economic losses due to fire can be used to guide fire prevention studies and fire extinguishing policies. In determining the cost of forest fires, the degree of fire impact on the forest product (goods and services) should also be considered in addition to fire extinguishing costs. One of the items affected by the fire is undoubtedly the timber product, which is one of the most important economic outputs of the forest. The loss in timber production can be considered under two main groups: 1) the timber product losses in the trees burned during the fire and 2) timber production losses resulting from the decrease in average increment as a result of early cutting of the stand that has not completed its management period due to fire. In this study, the economic consequences of improving forest road standards were evaluated by considering the economic value of timber products potential saved from the forest fires.

***Keywords:*** *Forest fires, forest roads, network analysis, timber products*

---

## 1. Introduction

Depending on the purpose of operating the forests, the extent of the damage caused by forest fires can be revealed. Especially if the purpose of the business is wood production, total economic losses can be calculated based on wood product losses caused by fire and market prices. If the forest facing the fire is young and the stems are thin, the forest is completely burned. In stands with thick stems, the leaves and thin branches burn, but the stems are subject to harvesting. On the other hand, the ages at which the annual average increase reaches its maximum in forests managed for wood production are determined as the management period (Eraslan, 1982; Kalıpsız, 1982) and management plans are prepared accordingly.

Considering the fact that if the forest that has suffered a fire is completely burned, it will be regenerated or afforested, there is an annual average increment loss equal to the stand age of the burned area. If the stems remaining intact from the burned area are subject to harvesting, there is a loss of timber production due to premature production of the stand before completing the management period. Erkan et al. (2009), the total wood production losses were calculated as 268,137.76 $m^3$ for the 12,390.1 hectares area damaged by the Serik-Tasagil forest fire in 2008 in Türkiye. Turker et al. (2002), in a case study they conducted, for a fire that broke out in Torul Forest Enterprise, taking into account the post-fire afforestation costs, they calculated the property damage per hectare as 770 TRY, the sapling damage as 307 TRY, the afforestation damage as 1276 TL, the extinguishing cost as 111 TRY and a total of 2464 TRY.

In order to effectively intervene in forest fires, especially in areas that are first-degree sensitive to fire, the transportation time of ground teams involved in firefighting to the fire area should not exceed the critical response time, which is more likely to be taken under control at the initial stage of the fire (OGM, 2008). For this reason, after receiving a fire alert, the optimum route that will enable the team that will move from the fire headquarter with a fire truck to reach the fire area as soon as possible should be determined in real time (Akay and Şakar, 2009).

Forest roads are key infrastructures that provide access to forest areas to protect forest resources. Approximately 66% of forest roads in Türkiye are B-type secondary forest roads (Akay et al., 2020). These roads are of limited standards and often require major repairs every year to ensure continued access to forest resources. In B-type secondary forest roads, the standard platform width is 4 m, the ditch width is 1 m and the total width is 5 m (Erdaş, 1997). The inadequacy of the technical standards used on these roads (platform width, curve radius, curve width, etc.) and the lack of engineering structures and superstructure negatively affect vehicle traffic (Buğday and Menemencioğlu, 2014). Increasing the design speed by improving the technical standards of these roads will make significant contributions to the expansion of accessible forest areas during the critical intervention period. Therefore, improving road standards and firefighting activities should be evaluated together.

Although improving road standards may cause some additional costs during the road construction phase, maintenance and repair costs will decrease significantly in the long term (Akay et al., 2020). Preliminary studies on this subject have shown that when the standards of forest roads are improved, accessible forest areas will increase significantly during the critical intervention period (Akay et al., 2021). In addition, the timely access of ground teams to larger forest areas will make significant contributions to reducing economic losses caused by fire-damaged wood raw materials.

In this study, the effects of improving the standards of forest roads were evaluated in terms of increasing the forest areas accessible by ground teams during the critical response time, especially in forests with high fire risk. When considered for business purposes, one of the factors most affected by the destruction caused by forest fires due to inability to reach them in time is the production of wood raw materials, which is one of the most important commercial purposes of forests. For this reason, the study aimed to investigate the effects of improving forest road standards on reducing economic losses arising from potential wood raw materials.

## 2. Material and Methods

### 2.1. Determination of Accessible Forest Areas

In this study, the potential contribution of improving the standards of forest roads in terms of expanding accessible forest areas with high fire risk during the critical response time was evaluated. In the solution process, first of all, forest areas that can be reached by ground team should be determined according to the critical response time, taking into account the existing road network in the study area. In the second scenario, the possible increase in accessible forest areas should be identified for forest roads with improved standards that enable high vehicle speeds.

The New Service Area method, which works based on network analysis under the Network Analyst in ArcGIS software, can be used to evaluate reachable forest areas during the critical intervention period for both scenarios. Critical response time varies depending on the degree of fire sensitivity in an area (OGM, 2008). Table 1 shows critical response times estimated by GDF based on long-term statistical data collected during wildfire events.

Table 1. Critical response times to fire sensitivity degrees (OGM, 2008)

| | Fire Sensitivity Ratings | | | | |
|---|---|---|---|---|---|
| | I | II | III | IV | V |
| Response Time | 20 min | 30 min | 40 min | 50 min | 50 min |

The New Service Area method works similarly to GIS “buffer” analysis. In this method, a service area point is first located in the network system and is considered a center point from which other parts of the network can be reached according to a user-defined total connection value threshold. This accessible area includes the service area. In this study, the locations where the ground teams are located represent the service area points, and the service areas represent the forest areas that can be reached within the total link value defined by the critical response time. The forest areas that teams can reach during the critical response time can be determined with this approach for both scenarios. Then, by taking the difference between the accessible forest areas in the second scenario and the accessible forest areas in the first scenario, additional forest areas that can be reached by improving road standards can be determined.

**2.2. Economic Consequence of Improving Road Standards**

When considered in terms of business purposes and economy, one of the items affected by fire is undoubtedly the wood product, which is one of the most important business purposes of the forest. The loss in wood production can be collected under two main headings. The first of these is the wood product losses in the trees burned during the fire. Such losses occur mostly in young forests and when the fire occurs in the form of a hill fire. The second is wood production losses resulting from the decrease in average increment as a result of early cutting of the stand that has not completed its management period due to fire. This second type of losses also occurs when the wood product in the burned forest is cut and sold without any damage.

This age, at which the average increase reaches its maximum, is used to determine the "highest wood revenue management period", and wood production losses occur in harvests made earlier or later than this age. As a result of this situation; even if there is no loss of quality or quantity in the existing wood product as a result of the fire, there is a loss of production due to harvesting before the completion of the management period of the forest.
The average increase is calculated with the following formula:

$$\Delta V_{o(i)} = \sum V_i / T_i \quad (1)$$

$\Delta V_{o(i)}$: i. General average annual increase of the stand ($m^3$)

$\sum V_i$ : i. Total volume of the stand in year T (including intermediate revenue) ($m^3$)

$T_i$ : i. Age of the stand

As can be seen from the formula, the average increase is calculated by dividing the total amount of wood produced by the forest up to a certain age by the age (Kalıpsız, 1982). If the primary purpose is the production of wood raw materials, the age at which the general average increase reaches its maximum is considered as the management period and is called the "highest wood revenue management period" (Eraslan, 1982).

When calculating the wood increment losses in the burned area, the general average increments per hectare are calculated for each stand type, based on the age of the fire in the year it broke out, site index and degree of closure, as early harvest is made due to fire:

$$\Delta V_i = f\left(T_i, SI_i, C_i\right) \quad (2)$$

$\Delta V_i$: *i*. Average annual increase of the stand ($m^3$/year/ha)

$T_i$ : *i*. Age of the stand (years)

$SI_i$ : *i*. Site quality degree of the stand

$C_i$ : *i*. Degree of closure of the stand

Then, assuming there is no fire, the general average increment per hectare can be determined for each stand type, taking into account the situation that it will be operated according to the management period determined in the plan. For this purpose, using Formula 2, the general average increment values per hectare for each stand type can be checked from the revenue table according to the management period, site index and degree of closure.

As mentioned above, if a fire does not occur, the forest will be operated according to the management period determined in the plan and "an annual average increase in hectares" will occur. However, due to the fire, there will be an early harvest and there will be an "average annual increase per hectare" in the age of the fire year. In order to calculate the total increment loss due to fire, the annual average increment difference in this hectare due to early harvest must be multiplied by the area of the relevant section and its age in the year of the fire.

## 3. Conclusion

Wood production losses can be taken as basis for calculating economic losses arising from fire. For this purpose, wood product losses should be converted into product types, and then the economic loss can be calculated by multiplying and adding each product type with the market product prices. The amount of area saved by early intervention to the fire (due to raising road standards) and the stand characteristics of this area are used to calculate the economic gain obtained according to the method explained above. Net profit can be calculated by deducting the expenses incurred to improve road standards. The net present value will be calculated by taking into account the years in which the expenses incurred, and the earnings obtained are incurred and discounting them to the present.

## Acknowledgement

This work was supported by The Scientific and Technological Research Council of Türkiye (TUBITAK, Grant number: 221O309).

**References**

Akay, A.E., Sakar, D. 2009. Yangın Sahasına En Kısa Sürede Ulaşımı Sağlayan Optimum Güzergahın Belirlenmesinde CBS Tabanlı Karar Destekleme Sisteminin Kullanılması. TMMOB Coğrafi Bilgi Sistemleri Kongresi. 02-06 Kasım. İzmir.

Akay, A.E. Serin, H., Sessions, J., Bilici, E., Pak, M. 2020. "Evaluating the Effects of Improving Forest Road Standards on Economic Value of Forest Products". Croatian Journal of Forest Engineering. 42(2).

Akay, A.E., Podolskaia, E., Uçar, Z. 2021. "Effects of Improving Forest Road Standards on Shortening the Arrival Time of Ground-based Firefighting Teams Accessing to the Forest Fires". European Journal of Forest Engineering, 7(1):, 32-38.

Buğday, E., Menemencioğlu, K. 2014. Türkiye'de Mevcut Orman Yolu Standartlarının Dikili Ağaç Satışına Uygunluğunun İrdelenmesi. II. Akdeniz Orman ve Çevre Sempozyumu. 22-24 Ekim. Isparta.

Eraslan, İ. 1982. Orman Amenajmanı Ders Kitabı, İ.Ü. Orman Fakültesi Yayın No: 318, İstanbul.

Erdaş, O. 1997. Orman Yolları. Cilt I-II. K.T.Ü. Basımevi. Yayın No:187. Trabzon. 744s.

Erkan, N., Yalçın, A., Aydın, A.C. 2009. Serik-Taşağıl Orman Yangınında Oluşan Odun Üretim Kayıplarının Kestirilmesi, Orman Yangınları İle Mücadele Sempozyumu, Bildiriler Kitabı, s.427-433, Antalya.

Kalıpsız, A. 1982. Orman Hasılat Bilgisi Ders Kitabı, İ.Ü. Orman Fakültesi, Yayın No:328, İstanbul.

OGM, 2008. Yangın Eylem Planı. Orman Genel Müdürlüğü. Kahramanmaraş Orman Bölge Müdürlüğü, Kahramanmaraş. 106 p.

# Analysis of Skidder Fuel Consumption by Work Operations During Timber Extraction – Case Study

**Marijan Šušnjar[1*], Zdravko Pandur[1], Marin Bačić[1], Hrvoje Kopseak[2]**

[1]University of Zagreb, Faculty of Forestry and Wood technology, Zagreb, Croatia
[2]Croatian Forests Ltd. Zagreb, Forest administration Bjelovar, Croatia
*msusnjar@sumfak.hr

## Abstract

Research was performed on the skidder Ecotrac 140V during timber extraction in mountainous terrain. The skidder was equipped with a measuring device WIGO-E (Telematic Data collector) gateway with an integrated GPS system, which ensured data were collected from sensors and motor and stored in a computer via CANBUS and data transfer with GSM to Web platforms. In order to precisely measure fuel consumption, a differential fuel consumption meter DFM 100CD was installed on the skidder, which has the ability to measure current fuel consumption and total fuel consumption. The measurement range covers the minimum flow rate of 10 L/h, the maximum flow rate of 100 L/h with an accuracy of ± 3%. Data on fuel consumption (mL), position (traveling route) and detection of winch work were measured with a sampling frequency of 5 s. Furthermore, skidder load volumes per cycles and slopes of skid roads were constantly measured. Based on the results of measuring the fuel consumption of the Ecotrac 140 V skidder when hauling wood at the same worksite for 8 working days), fuel consumption was determined by work components within each cycle and in total on working days.

***Keywords:*** *Skidder, fuel consumption, differential flowmeter, working cycles*

## 1. Introduction

Fuel consumption in logging is a major cost component of timber harvesting. Baker (2013) states that fuel has been found to make up 22.8% of the in-woods logging cost. Depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16 percent to over 45 percent of the total machine costs (Grisso, 2020). Temba et al. (2021) determined that fuel cost consumes 68.8 % of the total variable cost during work of the grapple skidder in the tree length harvesting system.

With an expected increase in the level of timber harvesting, coupled with greater levels of mechanization, we can expect higher levels of total fuel used in future harvesting operations. The ability to predict tractor fuel consumption is very useful for budgeting and management. Fuel prices are influenced by market forces beyond the control of logging contractors and stakeholders in the industry. This variability makes it difficult to forecast the impact of change to the logging industry (Oyier and Visser, 2016).

A lot of recent studies deal with fuel consumption rates of different timber harvesting systems including all forest machines in the production process (Ghaffariyan and Brown 2013, Ghaffariyan et al., 2015; Protto et al., 2017). Studies have shown that fuel consumptions of applied timber harvesting methods are affected by many factors, including operator characteristics, stand and terrain variables, as well as machine specifics (Klvač and Skoupy, 2009; Cosola et al., 2016; Ackerman et al., 2017). Fuel consumption rates for a single forest machine in timber harvesting system are affected by the engine size, load factor, condition of the equipment, operator's driving skill, environmental conditions, as well as the design of the machine (Kenney at al., 2014). According to Halilović et al. (2019) the following factors affect fuel consumption: external factors (climatic, field, stand), machine factors (engine, working and transmission part factors), technological factors (working method, work operations) and organizational factors (machine maintenance, operator education).

Comparison of fuel consumption rates among studies is sometimes very difficult because data is often published in different units: liters per unit of extracted timber (L/m$^3$), liters per productive machine hours (L/PMH) or scheduled machine hours (L/SMH), liters per unit of power (L/kWh), liters per unit weight of the machine (L/ton).

FP Innovations in Canada have produced a guide with suggestions for reducing fuel consumption rates which could be applied for any forest operation and include: use of diesel engines at maximum torque, avoiding thermostatic and hydraulically driven fans operating at full speed under all working conditions, use of the work lights only when required, minimizing idling, keeping the radiator and oil cooler clean, choosing appropriate tyres to minimize sinking and loss of traction and preferring downhill skidding and forwarding (Ghaffariyan et al., 2018).

In most countries of southern Europe use of skidders and agricultural tractors equipped with forest winches is the most common way of timber extraction (Spinelli and Magagnotti, 2011). There are only some studies available on the fuel consumption of skidders commonly used in middle and south, south-east Europe despite environmental and economic concerns on the fuel consumption, emissions and increasing fuel costs.

Holzleitner (2011) analyzing the efficiency of forest machines based on long-term data of forest machines of the Austrian Federal Forests in the period from 2004 to 2008, get the average fuel consumption per operating hour of the skidder in the amount of 7.3 L/PSH. Janeček and Adamovský (2012) concluded that TERRI 2040 clambunk skidder when skidding 1 m$^3$ of timber over a skidding distance 154–731 m consumed 0.52–1.30 L of diesel fuel.

Borz et al. (2013) investigated differences between fuel consumptions of skidders by considering logging distance and species group (resinous or broadleaved) when working in different stand conditions. Fuel consumption of skidders is always higher during timber extraction in broadleaved stands. According to Kenney et al. (2014) states skidders consume on average 3.31 L more per operating hour and 0.12 L more per m$^3$ compared to forwarders.

Kopseak et al. (2021) determined the average fuel consumption of for skidder in even-aged forests (1.38–1.65 L/m$^3$) and selective forests (1.06–1.34 L/m$^3$) which was higher than the study conducted Borz et al. (2013); 0.62 L/m$^3$ in conifers or 1.00 L/m$^3$ in deciduous trees. In the same study, the average fuel consumption in even-aged forests ranged from 7.81 to 9.34 L/PMH and from 6.49 to 7.10 L/PMH in selective forests. The results obtained are similar to the results reported by Holzleitner et al. (2011)—7.3 L/PMH—but significantly lower than the results reported by Enache et al. (2016): 12.5 L/PMH.

This can be explained by the fact that, in selective forests, due to the method of work, skidders extracted larger logs but there was a smaller number of load pieces and, ultimately, a larger volume of wood was extracted per load compared to the regular forest management, where the assortment method was used, and in a single load, there was a larger number of smaller load pieces and the total volume of load was smaller. Due to the larger number of pieces of logs in one load, more time was spent on hooking the load and on the operation of the winch, and thus, the fuel consumption in even-aged forests was significantly higher than the consumption of skidders working in selective forests.

Effective planning of the operations can reduce costs and improve work efficiency but this requires detailed information on productivity and cost of different timber harvesting operation as part of the planning process (Williams and Ackerman, 2016). Such information is also important for understanding the performance of forest machines and/or harvesting systems under varying stand and terrain conditions (Visser and Spinelli, 2012). Given the difference in operating conditions caused by variations in stand, working conditions and terrain factors, it is important to quantify the productivity and cost of each form in order to select the best option which suit specific local condition while optimizing the profitability of the logging operation (Temba et al., 2021).

In the area of the hilly and mountainous forests of Croatia, skidders with a winch weighing up to 10 tons are primarily used for timber extraction from regular felling of broadleaves and selective felling of coniferous species (Horvat et al., 2007). According to Tomašić et al. (2012), about 55% of the total timber assortments are extracted by skidders with a winch.

In Croatia the application of forest harvesting technology is particularly affected by specific features and characteristics of forest management. An exceptionally important feature of our forests is a high proportion of natural forests in the total forest area, which implies a more demanding forest management and more complex processes of forest regeneration and tending. According to the Forest Law, the forest Management Plan is the basic framework for regulating the management of forests and forest land based on the principle of sustainable production, natural regeneration and permanence of income while preserving and improving the diversity and other generally useful functions of forests. Forests on the territory of one forest management area are managed according to the provisions of the Forest Management Plan, which is drawn up for a period of ten years. In doing so, the total amount of felling is prescribed for each forest department, by tree species and economic classes (Forest Law, 2018).

The primarily aim of this research is to analyze fuel consumption of skidder during timber extraction from thinning of beech forest on mountain terrain. It should be emphasized the uniqueness and originality of the detailed analysis of skidder fuel consumption according to the working elements of the skidder tour, according to which guidelines can be given for better and more efficient organization of work and reduction of fuel costs. Furthermore, the suitability of the skidder and harvesting system will be considered based on the results of fuel consumption.

## 2. Materials and Methods

The research was conducted in the mountainous area in the Lika-Senj County. The data were collected from the work site in Management unit "Jadovno – Jazbine" department 5a, where the skidder was working in thinning of even-aged beech forest on mountain terrain. The age of the forest was 55 years. The area of forest compartment is 30,50 ha and growing stock is 247 $m^3$/ha. According to the Forest Management Plan total of 1548 $m^3$ were felled. The DBH of average felled tree was 24,8 cm with timber volume of 0,53 $m^3$.

Investigations were carried out on skidder Ecotrac 140V owned by Croatian Forests Ltd. Zagreb in the real work of timber skidding. Skidder load volumes per each cycle were constantly measured after unloading on the landing forest near forest road. A total of 8 working days were recorded at that worksite, and during that time the skidder extracted 126,90 $m^3$ of wood mass in 56 skidding cycles.

The work site was organized in such a way that the empty skidder drove uphill, and when loaded it moved downhill. During all days, the skidder was worked on the three skid roads (lengths 900 m, 440 m and 300 m) each with a continuous longitudinal slope of 8%. The research was performed during springtime among days without precipitation during rainy period in a mountainous region. The surface of the skid trail was very wet and muddy with wheel ruts up to 20 cm along the trail length. Technical characteristics of Ecotrac 140 V are shown in Table 1. For the purpose of collecting telemetry data, skidder was equipped with systems for managing and monitoring the operation of the vehicle, Fleet Management System (FMS).

Table 1. Technical characteristics of skidder Ecotrac 140 V

| | |
|---|---|
| Engine type | Cummins Inc, QSB4.5, diesel, 4-cylinder, water cooling |
| Power (kW/HP) | 104/140 |
| Torque (Nm) | 624 |
| Weight (kg) | 8060 |
| Tire size | 16.9-R30 |
| Winch | 2-drums, hydraulically driven, nominal pulling force 2 x 100 kN |

The basic component of the FMS is the mobile unit WIGO-E (Figure 1a). WIGO-E is a professional industrial IoT Gateway that collects and stores data from sensors us-ing different communication protocols, such as WLAN, LAN, and GSM. The data is sent via GSM protocol to the web platform where it is saved on the cloud. The mobile unit has a useful feature that in case of the absence of a GSM signal, which is often the case in forest conditions, it stores the measured data in its internal memory, which is retroactively sent to the server at the moment when the vehicle is in the signal receiving area. An integral part of the FMS is a GPS device that is used to record the position of the vehicle with an associated GPS/GSM antenna that enables the transmission of collected data and the reception of satellite signals for GPS operation (Figure 1b). In order to precisely measure fuel consumption, a differential fuel consumption meter - DFM 100CD is installed on the skidder, which has the ability to measure current fuel consumption and total fuel consumption. Regarding measurement range for this mod-el, the minimum flow rate is 10 L/h, and the maximum flow rate is 100 l/h with the ac-curacy ± 3% fuel flow with a precision of 0.001 L (Figure 1c). The fuel supply line to the drive engine passes through the meter, as well as the amount of fuel that is not consumed in the engine and returns to the fuel tank, passes through the meter and differential correction of fuel consumption is performed.


Fig. 1a - WIGO-E (Telematic Data Collector)

Fig. 1b - GPS/GSM antenna

Fig. 1c - Differential fuel consumption meter - DFM 100CD

Figure 1. Fleet management components which are installed on the skidder.

The data is accessed via the Mobilisis web platform. The system offers us the possibility of monitoring skidder operation in real time or we can generate reports for the parameters we monitor in the form of excel tables that are suitable for further processing and analysis. The parameters that are measured are: total fuel consumption (mL), skidder position - GPS data (latitude, longitude), time and duration of winch use, engine rpm ($min^{-1}$), engine torque (% of maximum), throttle position (%) and engine temperature. In addition to remote data collection, the amount of wood from each skidding cycle is recorded on the field.

The work cycle of the skidder was divided into the following working elements: the unloaded travel from the roadside landing to the felling area in the forest, the operation of the winch (pulling out of winch rope and winching of the load), travel of the loaded skidder to the roadside landing area and unloading. From the measurement data, the start and end times of each working cycle as well as each working element per cycle were determined. The values of the diesel fuel consumed measured in milliliters via the differential flowmeter were distributed based on measured time to working cyles and working elements.

## 3. Results and Discussion

Table 2 shows the summary of the dimensions of the timbers extracted in this study. Presented numbers indicate small piece size, a crucial factor that influences fuel consumption per volume of extracted wood. Corresponding to Table 2, Table 3 shows load volumes which are two to three times smaller than nominal capabilities of the observed skidder. Average daily load volumes are under 3 $m^3$.

Table 2. Timber extraction structure

| | Minimum | Total / Average | Maximum |
|---|---|---|---|
| Total skidded timber volume, $m^3$ | | 129,60 | |
| Total skidded number of pieces | | 577 | |
| Total number of cycles | | 56 | |
| Load volume, $m^3$ | 0,82 | 2,27 | 3,91 |
| Average number of pieces in load | 8 | 10,3 | 15 |
| Mean piece length, m | 2 | 6,4 | 10 |
| Mean piece diameter, cm | 10 | 20,4 | 52 |
| Mean piece volume, $m^3$ | 0,02 | 0,44 | 1,06 |

Table 3. Load volumes per cycles

| | Load volumes (m$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cycle | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Total |
| 1 | 2,19 | 2,47 | 1,76 | 2,42 | 0,82 | 3,04 | 1,82 | 2,43 | 16,94 |
| 2 | 2,22 | 1,83 | 1,70 | 2,58 | 1,73 | 3,03 | 3,91 | 2,87 | 19,88 |
| 3 | 3,06 | 2,04 | 0,89 | 2,15 | 2,13 | 1,10 | 2,28 | 2,52 | 16,18 |
| 4 | 2,67 | 2,12 | 1,47 | 3,11 | 1,41 | 2,75 | 2,46 | 2,42 | 18,41 |
| 5 | 1,83 | 1,17 | 2,04 | 2,80 | 2,66 | 2,15 | 1,98 | 1,50 | 16,12 |
| 6 | 1,63 | 1,86 | 1,54 | 3,16 | 2,76 | 3,61 | 2,57 | 1,93 | 19,06 |
| 7 | 3,09 | 2,35 | 2,77 | 2,52 | 2,89 | | | | 13,62 |
| 8 | 2,42 | 1,99 | 2,29 | | | | | | 6,70 |
| Total | 19,10 | 15,82 | 14,47 | 18,73 | 14,40 | 15,69 | 15,02 | 13,67 | 126,90 |
| Average | 2,39 | 1,98 | 1,74 | 2,68 | 2,06 | 2,62 | 2,50 | 2,28 | 17,76 |

Average fuel consumption (Table 4) per extracted volume of 2,09 L/m$^3$ is well over the ones reported by Borz et al. (2013) and Kopseak et al. (2021).

Table 4. Fuel consumption per cycles

| Fuel consumption per cycles (L) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cycle | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Average |
| 1 | 3,93 | 3,16 | 3,38 | 3,94 | 4,72 | 4,37 | 5,94 | 4,96 | 4,30 |
| 2 | 2,83 | 3,65 | 3,08 | 3,09 | 3,68 | 4,54 | 5,85 | 4,97 | 3,96 |
| 3 | 2,99 | 4,11 | 3,41 | 4,41 | 6,68 | 4,87 | 5,85 | 5,48 | 4,72 |
| 4 | 3,68 | 3,59 | 3,47 | 3,50 | 4,79 | 7,80 | 6,32 | 5,30 | 4,81 |
| 5 | 3,98 | 3,61 | 3,26 | 3,76 | 5,05 | 7,19 | 5,11 | 4,89 | 4,60 |
| 6 | 2,82 | 3,35 | 3,09 | 3,73 | 6,44 | 5,77 | 4,19 | 5,68 | 4,38 |
| 7 | 3,04 | 3,76 | 3,50 | 3,50 | 5,00 | | | | 3,76 |
| 8 | 3,72 | 2,83 | 3,19 | | | | | | 3,25 |
| Average | 3,37 | 3,51 | 3,30 | 3,70 | 5,19 | 5,76 | 5,55 | 5,21 | 4,33 |
| Fuel consumption per cycles (L/m$^3$) | | | | | | | | | |
| Cycle | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Average |
| 1 | 1,79 | 1,28 | 1,92 | 1,63 | 5,76 | 1,44 | 3,26 | 2,04 | 2,39 |
| 2 | 1,27 | 1,99 | 1,81 | 1,20 | 2,12 | 1,50 | 1,50 | 1,73 | 1,64 |
| 3 | 0,98 | 2,01 | 3,84 | 2,05 | 3,13 | 4,43 | 2,57 | 2,17 | 2,65 |
| 4 | 1,38 | 1,69 | 2,36 | 1,13 | 3,40 | 2,83 | 2,57 | 2,19 | 2,19 |
| 5 | 2,17 | 3,08 | 1,60 | 1,34 | 1,90 | 3,34 | 2,58 | 3,26 | 2,41 |
| 6 | 1,73 | 1,80 | 2,01 | 1,18 | 2,33 | 1,60 | 1,63 | 2,94 | 1,90 |
| 7 | 0,98 | 1,60 | 1,26 | 1,39 | 1,73 | | | | 1,39 |
| 8 | 1,54 | 1,42 | 1,39 | | | | | | 1,45 |
| Average | 1,48 | 1,86 | 2,02 | 1,42 | 2,91 | 2,52 | 2,35 | 2,39 | 2,09 |

According to Table 5, it was found that the skidder's fuel consumption is higher when moving an unloaded skidder uphill than when skidding wood downhill. When skidding small and insufficient loads regarding the size of the skidder, fuel is consumed primarily to obtain energy for the movement of the skidder.

Table 5. Fuel consumption per work cycle element

| | Fuel consumption per work cycle element (L) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cycle | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Average |
| Unloaded travel uphill | 1,39 | 1,24 | 1,17 | 1,10 | 1,70 | 2,12 | 2,74 | 2,25 | 1,65 |
| Loading (winching) | 1,01 | 1,16 | 0,90 | 1,20 | 1,24 | 1,31 | 0,97 | 1,29 | 1,12 |
| Loaded travel downhill | 0,33 | 0,47 | 0,60 | 0,59 | 1,10 | 1,28 | 1,13 | 0,81 | 0,76 |
| Unloading | 0,65 | 0,63 | 0,63 | 0,82 | 1,16 | 1,05 | 0,70 | 0,87 | 0,80 |

Figure 2 shows fuel consumption as a function of load volume and the results of this case study imply a very steep trendline with a strong coefficient of determination which confirms the piece size law. However, two additional trendlines of predicted 1 L/m$^3$ and 1,5 L/m$^3$, as reported by relevant literature, highlight individual loads where this kind of fuel consumption can be achieved. The volume of these loads starts from 2 m$^3$ onwards.

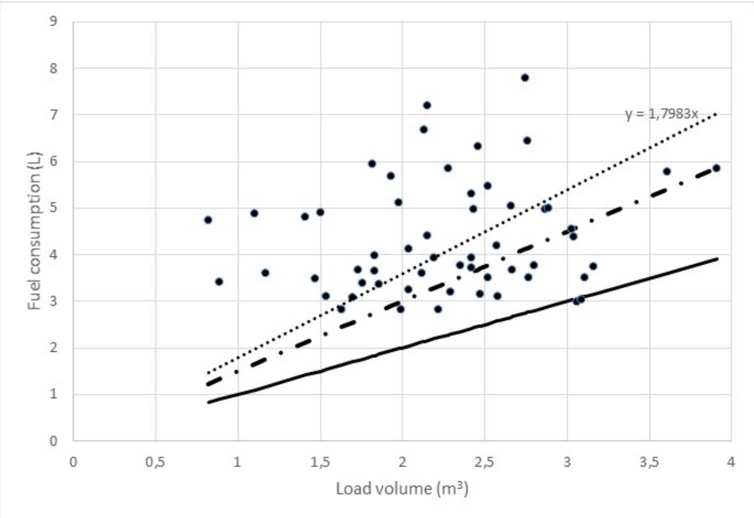



Figure 2. Fuel consumption vs load volume

## 4. Conclusions

The case study is part of a complex research of the skidder's energy consumption under different work tasks and under different field conditions, which was carried out during 272 working days of the skidder. This case study was chosen because the results of the research clearly indicate certain advantages and disadvantages of skidder operation during timber extraction. Analysis of fuel consumption by work components of the shift can provide guidelines for optimal work organization with the aim of reducing work costs. It can be concluded that it is more energy and cost-efficient to organize the work of the skidder to skid downhill.

In the organization of the skidder's work, field conditions have a great influence, primarily the processing method and the type of felling. The tested skidder (weighing over 8 tons) is not an optimal solution for pulling wood from early thinning. A large number of small pieces of wood in the load leads to greater consumption of time and fuel when working at the felling site, and an optimal load for that size skidder was not provided. In the tested conditions, when choosing the means of operation for the wood harvesting system, the use of another forest machine - a skidder of smaller mass and dimensions and/or a smaller forwarder - should have been considered in terms of energy and cost-efficiency.

On the other hand, there is a big organizational problem of Croatian forestry practice in the area of mountain forests. Beech and fir selective forests predominate in the mentioned area, and the Forest Service (Forestry Administration Office) primarily procures and uses skidders weighing more than 8 tons due to difficult terrain conditions. Even-aged forests are rarely represented in lower areas, and when implementing the regulations of the Forest Managemnet Plan, especially when carrying out thinning, forestry practice does not have satisfactory forest machinery. It should also be noted that no private enterprise has been developed in the forest sector for wood extraction works in the mentioned sub-region.

**References**

Ackerman, P., Williams, C., Ackerman, S., Diesel, C. 2017. Consumption and Carbon Balance in South African Pine Clear-Felling CTL Operations: a Preliminary Case Study CROJFE 2017.

Baker, S. A. 2013. Logging cost components of US timber producing regions and their use in a regional logging cost index. In: Proceedings of the 36th Council on Forest Engineering, July 7-10, 2013, Missoula, Montana.

Borz, S. A., Ignea, G., Oprea, I., Ciobanu, V., Dinulica, F. 2013. "A Comparison In Terms Of Carbon Emissions, Cost And Productivity Of The Most Used Technologies In The Young Thinned Stands – The Case Of Romania," Romanian Journal of Economics, Institute of National Economy, 37-2(46):67-79.

Cosola, G., Grigolato, S., Ackerman, P., Monterotti, S., Cavalli, R., 2016. Carbon footprint of forest operations under different management regimes. Croatian Journal of Forest Engineering 37(1): 201–217.

Enache, A., Kuehmaier, M., Visser, R., Stampfer, K. 2016. Forestry operations in the European mountains: a study of current practices and efficiency gaps, Scandinavian Journal of Forest Research, 31:4, 412-427, DOI: 10.1080/02827581.2015.1130849

Forest Law. 2018. Official gazette of the Republic of Croatia. Narodne novine 68/2018.

Ghaffariyan, M.R., Brown, M.W. 2013. Selecting the efficient harvesting method using multiple-criteria analysis: A case study in south-west Western Australia. Journal of Forest Science, 59(12), 479–486. https://doi.org/10.17221/45/2013-JFS

Ghaffariyan, M.R., Apolit, R., Kuehmaier, M. 2015. Analysis and control of fuel consumption rates of harvesting systems: A review of international studies Mohammad. Industry Bulletin 15.

Ghaffariyan, M.R., Apolit, R., Kuehmaier, M. 2018. A Short Review of Fuel Consumption Rates of Whole Tree and Cut-To-Length Timber Harvesting Methods. Current Investigations in Agriculture and Current Research, 5(2), 603–606. https://doi.org/10.32474/CIACR.2018.05.000209

Grisso, R. 2020. Predicting Tractor Diesel Fuel Consumption. VCE publication 442-073. Virginia Tech, Virginia State University. 1-11.

Halilović, V., Music, J., Bajrić, M., Soković, Dž., Knežević, J., Kupusović., A. 2019. Analiza potrošnje goriva pri sječi i izradi stabala hrasta kitnjaka na području p.j. šumarija „Zavidovići", Šumarski list, 7–8 (2019): 337–346.

Holzleitner, F., Stampfer, K., Visser, R., 2011. Utilization rates and cost factors in timber harvesting based on long-term machine data. Croatian Journal of Forest Engineering, 32(2):501-508.

Horvat, D., Ž. Zečić, M. Šušnjar, 2007. Morphological characteristics and productivity of skidder ECOTRAC 120V, Croatian Journal of Forest Engineering 28.

Janeček A., Adamovsky R., 2012. Optimisation of a clam bunk skidder from the emission production point of view. Res. Agr. Eng., 58: 136–141.

Kenney, J., Gallagher, T., Smidt, M., Mitchell, D., McDonald, T. 2014. Factors that Affect Fuel Consumption in Logging Systems. In: Proceedings of the 37th Council on Forest Engineering. June 22-25, 2014, Moline, Illinois. 1-6.

Klvac, R., Skoupy, A. 2009. Characteristic fuel consumption and exhaust emissions in fully mechanized logging operations. Journal of forest research. 14(6):328-334.

Oyier, P., Visser, R. 2016. Fuel consumption of timber harvesting systems in New Zealand Eur J Forest Eng 2(2): 67-73.

Proto A.R., Bacenetti J., Macri G., Fiala M., Zimbalatti G. 2017. Mechanisation of different logging operations: environmental impact assessment using life cycle assessment (lca) approach, Chemical Engineering Transactions, 58, 229-234 DOI: 10.3303/CET1758039

Spinelli, R., Magagnotti, N. 2011. The effects of introducing modern technology on the financial, labour and energy performance of forest operations in the Italian Alps. For. Pol. Econ. 13, 520–524.

Temba, G.P., Mauya, E.W, Shemwetta D.T.K. 2021: Modeling Productivity and Costs of Mechanized Tree Length Skidding Operations. Tanzania Journal of Forestry and Nature Conservation, Vol 90, No. 3 (2021) Special Issue: Embracing Science and Technology in Nature Conservation. pp 62-73.

Tomašić, Ž. 2012: Razvoj tehnlologije i tehničkih sredstava u pridobivanju drva s obzirom na posebnosti šuma i šumarstva u Republici Hrvatskoj, Nova mehanizacija šumarstva 33.

Visser, R., Spinelli, R. 2012. Determining the shape of the productivity function for mechanized felling and fellingprocessing. Journal of Forest Research, 17, 397-402.

Williams, C., Ackerman, P. 2016. Cost productivity analysis of South African pine sawtimber mechanised cut-to length harvesting. Southern Forests: a Journal of Forest Science, 78, 267-274.18. Holzleitner, F.; Stampfer, K.; Visser, R. Utilization rates and cost factors in timber harvesting based on long-term machine data.

# Assessing the Productivity of Timber Extraction with Lewis Winch

**Neşe Gülci[1], Abdullah E. Akay[2], Hasan Yılmaz[1], M. Emre Yiğit[1], H. Hulusi Acar[3]*, John Sessions[4]**

[1]Kahramanmaras Sutcu Imam University, Faculty of Forestry, Kahramanmaras, Türkiye
[2]Bursa Technical University, Faculty of Forestry, Bursa, Türkiye
[3]Istanbul Yeni Yuzyıl University, Faculty of Health Sciences, Occupational Health and Safety, Istanbul, Türkiye
[4]Oregon State University, College of Forestry, Department of Forest Engineering, Corvallis, USA
*hafizhulusi.acar@yeniyuzyil.edu.tr

## Abstract

Chainsaws are widely favoured equipment for timber production in Türkiye. Chainsaws are commonly used in various stages of timber production, including tree felling, tree bucking, and log debarking. In forest operations, manpower and cable-based pulling operations with tractors are commonly utilized for timber extraction from compartments. In Türkiye, where mountainous terrain is predominant, uphill timber extraction poses a significant challenge, especially in areas where forest roads are not planned. In such cases, unplanned temporary forest roads are constructed for timber skidding purposes, leading to damage to the stands. Therefore, this study investigated uphill pulling using the Lewis winch mounted on a chainsaw. The study was conducted in the forests of the Kahramanmaraş Regional Directorate of Forestry in Türkiye. In this study, time measurements were conducted to assess the extraction of small-diameter logs from a stand by uphill winching for various skidding distances on moderately sloped terrain. Productivity analyses were conducted using the SPSS statistical software. The average operating productivity of the chainsaw winch was determined as 1.99 $m^3$/hour. The study results demonstrated that utilizing the Lewis winch could provide an alternative method for extracting small-diameter logs uphill in areas without forest roads. Moreover, it has been suggested that chainsaws, widely employed in Türkiye, can also be utilized for uphill timber winching in small-scale forestry operations.

***Keywords:*** *Small-scale forestry, chainsaw, Lewis winch, small-diameter timber, productivity*

## 1. Introductions

Several timber extraction machines are used during the logs timber extraction operation to be delivered to the landing areas where they will be loaded onto trucks (Erdaş et al., 2014). In Türkiye, especially in mountainous areas, the timber extraction is mostly done by manpower, cable pulling with modified and powered farm tractor and forest tractors (Öztürk and Akay, 2007; Gülci, 2020; Taş et al., 2024). This situation is challenging for uphill timber extraction in the mountainous areas where roads are inadequate or do not exist.

In many countries, mechanical production machines have replaced the traditional logging methods. In timber extraction operations, logs are generally carried to the landing by a skidder or a forwarder, or a combination of both (Kellogg et al., 1992). In Türkiye, cut-to-length methods are mostly used in the log production. Small hand winches are an efficient alternative for timber extraction from the mountainous areas where roads cannot be constructed due to topographical limitations. There are previous studies that investigated the timber extraction productivity of mobile winches in Türkiye (Gülci et al., 2016a; Gülci et al. 2016b; Gülci et al., 2017a; Gülci et al., 2017b). However, there is no study on the chainsaw-powered Lewis winch. In this study, the productivity of Lewis winch was analyzed for various skidding distances on moderately sloped terrain.

## 2. Material and Methods

The study area was selected from Kahramanmaraş Forest Enterprise located in Mediterranean region of Türkiye (Figure 1). The field studies were carried out in Brutian pine *(Pinus brutia* Ten.) tree species. The average skidding distance was 30 meters and skid road slope was 30%.


Figure 1. Geographical location of study area

Timber extraction operations were performed by using a Castor 600i chainsaw-powered Lewis winch (Figure 2). The uphill winching with a chainsaw winch was implemented using steel rope, skidding cone, chain choker, polyester choker, and metal locks.

Figure 2. A Castor 600i chainsaw winch and skidding cone

Work stages evaluated were carrying choker to the logs, choker setting, uphill winching, and releasing the logs from the chokers. Time measurement of the work stages was performed for total of 30 trips by using repetitive time measurement with the help of chronometers. Productivity analyses were conducted using the SPSS statistical software.

## 3. Result and Discussion

The statistical results of productivity variables were given in Table 1. According to the results, the average diameter, length and volume were determined as 22.5 cm, 1.21 m and 0.10 $m^3$, respectively. It was found that average uphill winching time and average total cycle time were determined as 2.16 min and 2.94 min, respectively (Table 2). It was also found that uphill winching time was the most time-consuming work stage (73%). Carrying chokers to the logs was found to be the second time-consuming work stage (12%), followed by releasing the logs from the chokers (6%) (Figure 3).

Table 1. Productivity variables

| Variables | Min. | Max. | Mean | Std. Deviation |
|---|---|---|---|---|
| Diameter (cm) | 18.0 | 28.0 | 22.5 | 2.78 |
| Length (m) | 1.20 | 1.40 | 1.21 | 0.06 |
| Volume ($m^3$) | 0.07 | 0.13 | 0.10 | 0.02 |

Table 2. Time required by work stage

| Work stages | Min. | Max. | Mean | Std. Deviation |
|---|---|---|---|---|
| Carrying choker to the logs (min.) | 0.29 | 0.43 | 0.36 | 0.04 |
| Choker setting (min.) | 0.18 | 0.35 | 0.26 | 0.05 |
| Uphill winching (min.) | 1.58 | 3.15 | 2.16 | 0.22 |
| Releasing the logs from the chokers (min.) | 0.12 | 0.21 | 0.17 | 0.03 |

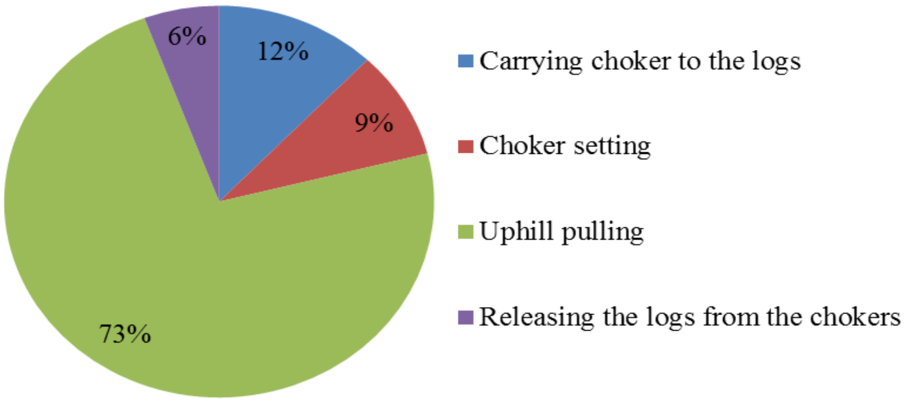



Figure 3. Percentage of work stages

The total time and productivity increases as timber volume increases (Figure 4). Previous studies have shown similar results with our results (Gülci et al., 2016a; Gülci et al. 2016b; Gülci et al., 2017a; Gülci et al., 2017b).

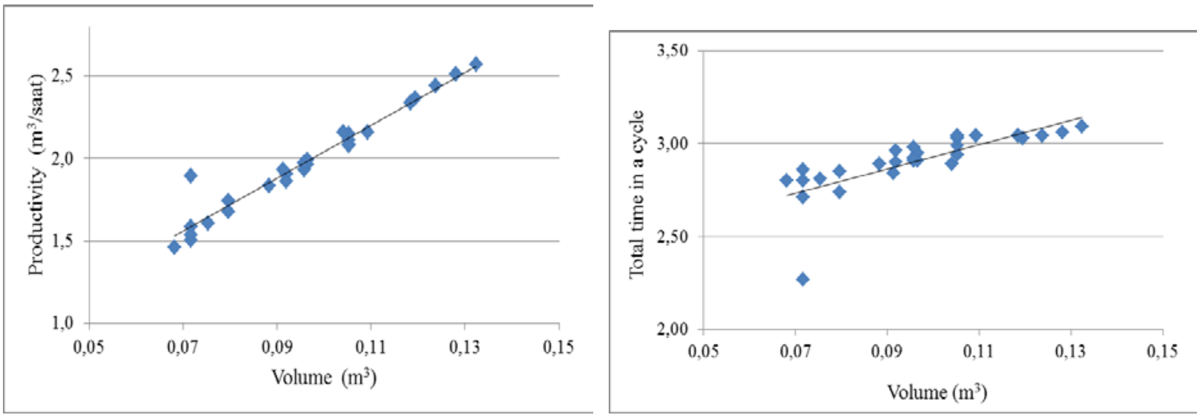


Figure 4. The relation between volume and total time, and volume and productivity

## 4. Conclusion and Suggestions

In this study, the timber extraction with a chainsaw- powered Lewis winch was investigated in terms of productivity. The average operating productivity of the chainsaw winch was determined as 1.99 $m^3$/hour. The study results suggest that the chainsaw winch will be an alternative method, especially in terrain conditions where the use of a farm tractor is impossible or uneconomical. The combined use of a chainsaw winch with a skidding cone or chute system can minimize the damage that may occur to the residual stand and forest soil. At the same time, using it on snow in winter will also increase productivity.

## References

Erdaş, O., Acar, H.H., Eker, M. 2014. Forest transportation techniques (Orman ürünleri transport teknikleri). Karadeniz Technical University, Faculty of Forestry, Trabzon (Turkish)

Gülci, N., Akay, A.E. Erdaş, O. Acar, H.H., Wing, M. 2016a. Controlled sliding of logs downhill by chute system integrated with portable winch and synthetic rope. İstanbul Üniversitesi Orman Fakültesi Dergisi, 66(1):256–263.

Gülci, N., Gülci, S., Yüksel, K. 2016b. Evaluating of uphill timber skidding with forestry tractor, Middle East Journal of Science, 2(1):58–63.

Gülci, N., Akay, A.E. Erdaş, O. Acar, H.H. 2017a. Productivity Analysis of Chute System integrated with Portable Winch and Synthetic Rope for Uphill Logging Operation. European Journal of Forest Engineering, 3(2):72–77.

Gülci, N., Yüksel, K., Akay, A.E. 2017b. Productivity assessment of portable hand winch based skidding operation on snow cover. Kastamonu University Journal of Forestry Faculty, 17(1):124–131.

Gülci, S. 2020. Productivity of a farm tractor with single drum winch during whole-tree timber extraction. Šumarski List, 144(1–2):43–43.

Kellogg, L.D., Bettinger, P., Robe, S., Steffer, A. 1992. Compendium of Mechanized Harvesting Research. Forest Research Laboratory, Oregon State University, Corvallis, OR. 401p

Öztürk, T., Akay, A. E. 2007. Modifying farm tractors for forest harvesting operations. Bottlenecks, Solutions, and Priorities in the Context of Functions of Forest Resources, 1111–1120.

# Productivity and Challenges of Combined Forest Management in Japan: A Case Study of Wasabi and Timber Production

**Noriko Sato[1*], Minako Iwata Inoue[2], Tetsuhiko Yoshimura[3]**

[1]Kyushu University, Faculty of Agriculture, Department of Agro-Environmental Sciences, Fukuoka 819-0395, Japan
[2]Himitsukichi, Craft Workshop, Hiroshima 734-0021, Japan (former student at Kyushu University)
[3]Shimane University, Faculty of Life and Environmental Sciences, Matsue 690-8504, Japan
*sato.noriko.842@m.kyushu-u.ac.jp

**Abstract**

Small-scale forestry operations are constrained by the income generated from timber sales owing to their limited area; therefore, it is crucial to identify alternative sources of revenue. A combination of forest management and agroforestry is anticipated to enhance management by forest owners and rural people in terms of the multifaceted utilization of forests. However, these approaches may diminish timber extraction productivity. The objective of this study was to elucidate the advantages and challenges of integrated management, as exemplified by a case study of a forest owner engaged in the cultivation of one of Japan's non-timber forest products, wasabi (*Eutrema japonicum* (Miq.) Koidz.), and timber. Wasabi is a speciality forest product cultivated in forests and is of significant cultural importance in Japanese cuisine. Data were obtained from interviews with a forest owner who owns approximately 80 ha of forest and is cultivating wasabi in Hita City, Oita Prefecture, Japan. In addition to production cost and sales data, labor diaries were used to calculate thinning productivity and seasonal labor allocation. Wasabi is grown on the forest floor and along mountain streams and is a labor-intensive product. Thinning is a management practice aimed at regulating the light environment in forests for wasabi production. The thinning was conducted using a mini-forwarder unique to Japan. While the dispersion of forestland represents a constraint for timber production for small forest owners in Japan, the ability to stagger the harvesting of wasabi at different elevations has enabled harvesting by family labor, thereby increasing the rate of return. The challenges include the difficulty of removing large-diameter timber and its low price.

***Keywords***: *Non-timber forest products, wasabi, mini forwarder, spur road, thinning, Japan*

## 1. Introduction

Agroforestry research is one of the most important aspects of the combination of agriculture and forestry management. According to the Web of Science, on September 10, 2024, 4,718 studies were identified with the term 'agroforestry' in the title. Many developments in agroforestry research have been achieved in developing countries in the field of agroforestry research, and many of the studies have discussed changes in crop yields and institutional design for participatory forest management and forest conservation (Liu et al., 2019, Mukhlis et al., 2022). The evaluation axis of agroforestry aims to achieve poverty alleviation and environmental conservation simultaneously (Tranchina et al., 2024). Although there is much interest in yield changes in agricultural products that are important to farmers' livelihoods, there has been little research on the productivity of timber harvesting and removal.

However, studies on forestry families written in Japanese have been evaluated from the perspective of achieving year-round employment of the family's labor force and securing income through combined agriculture and forestry operations, rather than from the perspective of multiple uses of forest land (Sato and Koroki, 2006). Most of the research in Japan focuses on agroforestry, which is a land-use system with a complex management system, and agroforestry research is still scarce. Therefore, this study reports the results of a survey of the actual situation of combined management of forestry and horseradish production and the productivity of timber harvesting, based on information from a forest owner who cultivates wasabi, a plant endemic to Japan, as a case study.

## 2. Materials and methods

Here, we explain some of the characteristics of wasabi production. Wasabi is endemic to Japan and is an indispensable spice in the Japanese food culture. The ground root is used as a spice when eating raw fish such as sushi and sashimi, the leaves and flowers are eaten in salads, and the leaves and stems are processed and used in pickles or marinated in soy sauce.

There are three methods to produce wasabi, as shown in Table 1. Generally, A and B are called “land wasabi” and C is called “water wasabi”. The highest unit price per kg is fetched for C, for which the roots could be cultivated. It is grown in terraced rice paddies with stones and sand in water in mountainous areas and mountain streams with cool, clear water. On the other hand, the stems and leaves of A and B are mainly harvested for processing; in particular, the seeds are harvested from wasabi grown in forests. Although the production period is longer than that of the others (3–4 years), cultivation method B is used as an agroforestry crop that takes advantage of natural conditions. The wood shown in the photograph is from a Japanese cedar tree approximately 50 years old.

According to statistics from Japan's Ministry of Agriculture, Forestry, and Fisheries, production of wasabi in Japan has halved in the 15 years from 2005 to 2020, with imports from China and processed products with the taste of wasabi becoming popular in recent years. The decline in production is attributed to the aging of producers, as well as to the higher temperatures of mountain stream water due to global warming and damage to mountain stream terraces used for growing water horseradish due to heavy rainfall (Yamane, 2024).

In this study, we investigated the actual situation and challenges in the management of Mr. S, a forest owner in Hita City, Oita Prefecture, who has been continuing wasabi production as a family business and has been expanding the scale of his business in recent years. He practices all three methods of horseradish cultivation, with particular emphasis on agroforestry (B), which is the production of horseradish in the forest, and also practices wood thinning as a family business. Data collection was undertaken based on interviews and participant observations as well as product sales and work diaries to examine the combination of wasabi and timber production and the productivity of timber production in 2015 and 2024.

The case study site is a mountainous area in Hita City, Oita Prefecture, Japan (Figure 1). Oita Prefecture ranks 7th among the 47 prefectures in Japan in terms of wood and wasabi production. Hita City in the Oita Prefecture is located in the southern part of Japan's four main islands, an area where cedar plantations have flourished for approximately 300 years. The average annual temperature in the Hita area is 15.4 °C and annual precipitation is 1,810 mm (Japan Meteorological Agency).

Table 1. Wasabi production methods and characteristics of each method

| Methods | A. Land wasabi, Greenhouse | B. Land Wasabi, Woodland | C. Water wasabi, Stream |
|---|---|---|---|
| Growing period | 6 months | 3-4 years | 15 months |
| Products | Flour, Leaves, Stems | Flour, Leaves, Stems, **Seeds** | Leaves, Stems, **Roots** |
| Notes | *Transplanting and promoting cultivation of woodland Wasabi<br>*Requires temperature and water control<br>*Mainly for processing<br>*C5Concentrated havest season | *Natural cultivation after soil preparation, seeding and fertilization<br>*Need sunlight through trees<br>*Light environment is regulated by thinning<br>*For raw food and for processing<br>*Long harvest season | *Requires water flow constantly with a cool temperature<br>*Terraced paddy fields made of stones and sand<br>*Operation in water |
| Photo of wasabi production in Mr.S |  |  |  |

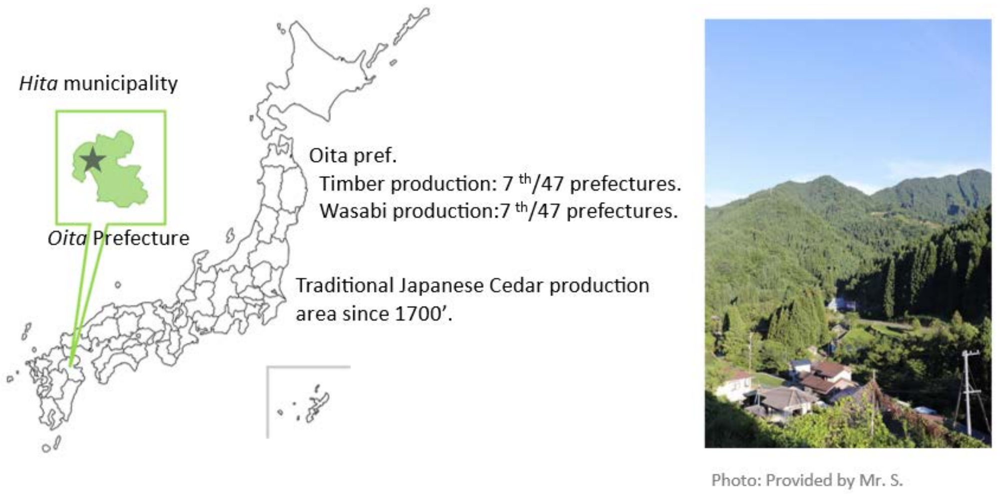



Figure 1. Location and landscape of the case study site

## 3. Results

### 3.1 General Information of the Case Study

Family S, chosen as a case study, is a self-employed agroforestry family that currently consists of the head of the household (61 years old) and his wife (58 years old), who produce and sell horseradish and forestry products. The family owns 0.7 ha of farmland and 80 ha of forest land. The company purchased approximately 10 ha of logged forestland over the past 10 years. On the farmland, the family grows rice and vegetables for their consumption and also produces horseradish in a plastic greenhouse on 0.1 ha of land. The forest land was planted with cedar (90%), cypress (10%), and coniferous trees, with biomass accumulation of approximately 450 $m^3$ per hectare. The forest cover is even in age, mostly 60–70 years old. The forest is dispersed across 14 sites, with each site ranging from 0.1 ha to 15 ha in area, and is characterized by fragmentation and differences in elevation. In the forest area, three sites (2 ha) suitable for wasabi production on the northern slope are growing wasabi under cedar; in 2015, the area was 1 ha suggesting that wasabi production has expanded in recent years. To prevent continuous crop damage, seeds are sown at different locations each year, and forest areas cultivated for 3–4 years are left fallow and thinned after a few years. The annual production of thinned wood is approximately 350 $m^3$. The company also produces water horseradish in an area of 0.02 ha along a mountain stream that runs through the forest.

The company owns a bush cutter, chainsaws (two units), a mini-forwarder with winch (1.2 t), a power shovel (3 t, 0.1 $m^3$), a light truck (350 kg, 660cc, 4WD), and a buggy. The company is relatively small in scale and their initial investment in machinery is relatively low.

**3.2 Wasabi Production and Sale**

Family S produces horseradish using three different cultivation methods; Table 2 describes the sales value and methods in 2023. The highest sales value was for land wasabi by agroforestry in B, indicating that, in addition to leaves, stems, and flours, seed sales are important to the management.

Table 2. Wasabi products sale according to the production method

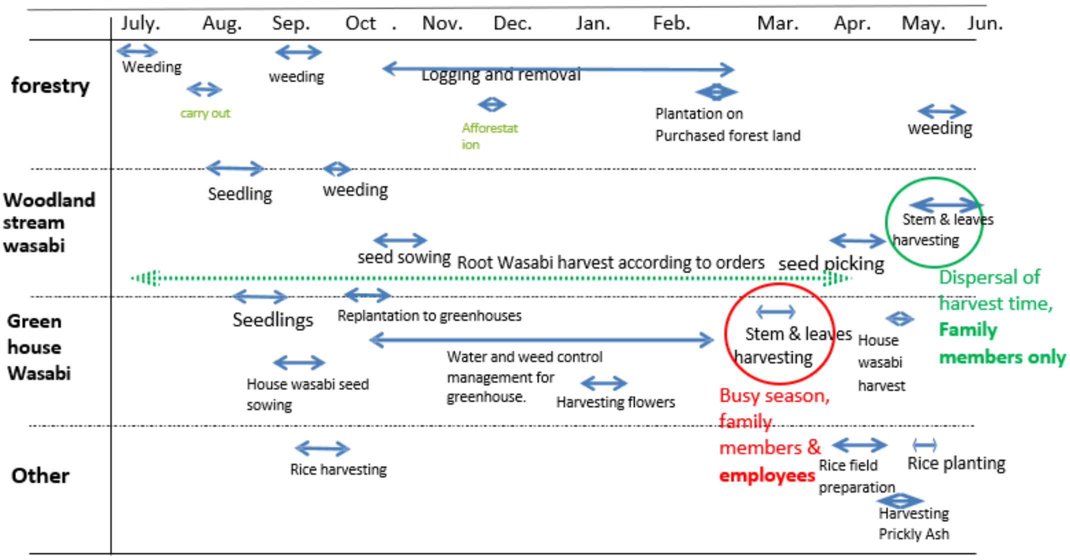
| Methods | A. Ground greenhouse | B. Woodland | C. Stream |
|---|---|---|---|
| Growing period | 6 months | 3-4 years | 15 months |
| Products | Stems, Leaves, Flours | Leaves, Stems, Flours, **Seeds** | Leaves, Stems, **Roots** |
| Sites | 1 site, 0.1ha | **3sites, 2ha** | 1 site, 0.02ha |
| Sales amount | leaves, stems, flours:<br>0.5mill yen (3,000EUR) | Leaves, stems, flours:<br>2.5mill yen (16,000EUR)(incl. Stream)<br>seeds: 1.2mill yen (8,000EUR) | roots:0.4mill yen (2,700EUR) |
| Sales to | All to wholesalers | leaves, stems, flours:<br>50% to consumers and restaurants,<br>50% to wholesalers<br>Seeds:<br>100% to directly producers | All to consumers and restaurant<br>(Sushi bar, Soba noodle bar) |

Source: interview and sales slip (2023)

Based on the sales methods listed in Table 2, all of the wasabi grown in the greenhouse is shipped to the wholesale market, but half of the wasabi leaves, stems, and flowers is sold directly to consumers and restaurants, whereas the other half is sold at the wholesale market. Seeds are sold directly to producers, and all of the wasabi roots grown along steams is sold directly to consumers and restaurants. In recent years, Family S has made an effort to increase the proportion of direct sales. The wife also teaches consumers how to cook horseradish during cooking classes. Because of the decline in consumption due to the young generation's general avoidance of traditional food as well as the decline in production, the wholesale market price is stagnant, making it challenging for the family to develop their own market.

Wasabi produced using method A is sold completely to a wholesale market because the harvest season is concentrated, and it is not possible to secure labor for packaging and shipping. In the case of agroforestry B, production is carried out at three sites at different altitudes (500 m, 600 m, and 900 m). Table 3 shows the work involved in forestry and wasabi cultivation work based on field diaries and participant observations from July 2014 to June 2015. The cultivation of wasabi in three locations at different altitudes is designed to spread out the harvest period and make it possible to harvest with family labor; production in distant locations is also considered a way of dealing with the risk of pathogens.

Table 3. Labor allocation based on annual work diary (2014-2015)




Source: Work logbooks, interview and participant observation

### 3.3 Timber Production by Thinning

The forestry work is primarily undertaken by the heads of household. The thinning and felling are carried out between October and February. Approximately 200 m length of spur roads per hectare are available in the forest, through which mini-forwarders can pass. An image of the forestry operations is shown in Figure 3. After felling with a chainsaw, the logs are pulled up to the work path using a mini-forwarder winch and then transported to the forest road by truck. Felled trees can be placed on or near the work path because of the dense network of roads. The mini-forwarder can carry one ton in weight and makes approximately five round trips per day, producing approximately 5 $m^3$ per day of logs from felling to removal to the forest road. The logs removed from the forest road are transported to the lumber market in trucks arranged by the forestry cooperative.

The mini-forwarder is manufactured by an agricultural machinery company and owned by many small-scale self-employed forest owners in Japan. Mr. S has been using this mini-forwarder for over 20 years, and as it has already depreciated, the only annual expenses are fuel costs and sales commissions. The logging and removal productivity of 5 $m^3$ per day is higher than the average productivity of thinning in Japan, which is 4.35 $m^3$ per person per day (MAFF, 2018), and the low cost of the machine suggests that it is clearly highly profitable. This mini-forwarder was developed in the 1970s. It weighs 900 kg and has a load capacity of 1.2 tons. The engine has a volume of 479 cc and the mini-forwarder can move forward and backward.

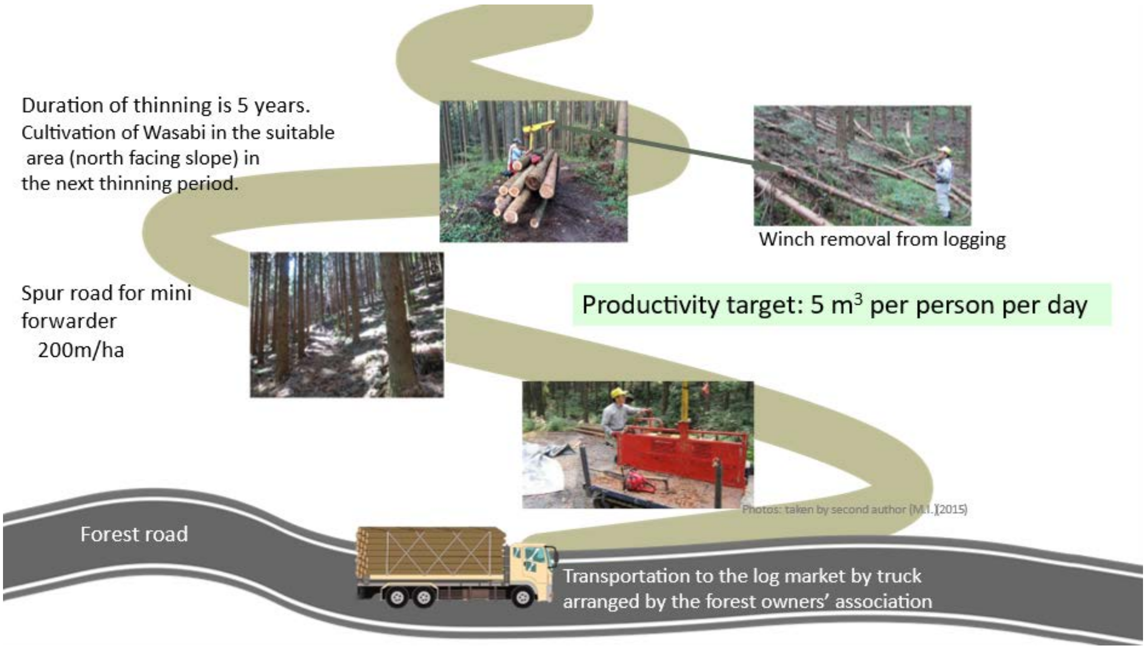



Figure 2. Image of S's Forestry operation

Thinning is conducted once every 5–10 years and wasabi is planted only after thinning is completed, when the light environment is appropriate. The production period of forest hill horseradish is 3–4 years, and there is no concern about damaging the horseradish during thinning. In other words, wasabi production does not negatively affect the harvest productivity of timber. Rather, Mr. S emphasized in the interview that because he often visits the forest for wasabi production, he frequently uses the work roads, which keeps the roads well-maintained and lowers the cost of wood production.

Mr. S has no plans for clear-cutting forests in the immediate future. Even if he clears the forest in the future, he plans to do it at a small scale (less than 1 ha). In recent years, there have been cases of nearby forest owners leaving forests after clear-cutting, and where the location is suitable, they have purchased land and planted trees to the extent that they can do so with their own labor.

**3.4 New Challenges**

Mr. S is taking on various challenges to pass the business on to his eldest son, while continuing the combined management of wasabi and forestry. The first challenge is to develop new sales methods for wasabi. He is considering the possibility of increasing demand for wasabi in the midst of the recent global boom in Japanese cuisine but is cautious about exporting the seeds of endemic species, as there is a risk that the producing country may be replaced. We are considering ways to achieve this goal.

The second is to make effective use of forest land for agroforestry and turn the forest into a service industry by operating a campground. As they are growing three types of asabi, they have received many visitors in the past and the forestry business was explained to them.

Thirdly, as the age of a forest increases, it may become more difficult to harvest trees using a mini-forwarder. Therefore, new machinery systems, such as machines with grapples, may need to be introduced.

## 4. Discussion and Conclusions

It is not feasible to derive comprehensive insights into the advantages and disadvantages of combined agriculture and forestry using a single case study. Nevertheless, the following points are evident. In mountainous regions, where agricultural land is scarce, forests can be utilized effectively to provide year-round employment through agroforestry, thereby enabling full-time management with income sources beyond forestry alone. In the case of wasabi, the growing period is three years, which allows for its cultivation between the implementation periods of thinning, thus not affecting timber production.

Work-roads are frequently used for wasabi production and are duly maintained for each instance of use. This results in the implementation of a forestry cost-saving strategy. Although forest fragmentation is typically an impediment to effective management, it can reduce the risk for wasabi production. Forest owners currently face the challenge of reviewing their working systems to adapt for large-diameter timber harvest.

The decline in the consumption of both timber and horseradish is causing prices to decline. Companies seek to sell directly to consumers; however, the limitations of family-run businesses present obstacles. Producer groups and cooperatives may need to collaborate on joint efforts to address this challenge. We did not consider this aspect, but it needs to be evaluated from the biodiversity perspective of agroforestry and combined forest management.

**Acknowledgements**

This work was supported by JSPS KAKENHI, Grant Numbers 25292090 and 24H00781. We thank Mr. Manabu Sato for his assistance with data collection.

**References**

Forestry Agency, 2020. Ministry of Agriculture, Forestry and Fisheries, Japan. Annual Report on Forest and Forestry in Japan.

Liu, W., Yao, S., Wang, J., Liu, M. 2019. Trends and Features of Agroforestry Research Based on Bibliometric Analysis. Sustainability, 11: 3473.

Mukhlis, I., Rizaludin, M.S., Hidayah, I. 2022. Understanding the socioeconomic and environmental impacts of agroforestry on rural communities. Forests,13: 556.

Sato, N., Koroki, K. 2006. Theory of Forestry Household Management (The Japanese Forest Economic Society (ed.), Issues in Forestry Economics Research; 50 years of progress, J-FIC, Tokyo), 233-254 (in Japanese).

Tranchina, M., Reubens, B., Frey, M., Mele, M. 2024. Mantino, A. What challenges impede adoption of agroforestry practices? A global perspective through a systematic literature review. Agroforestry Systems, 98(6):1817-1837.

Yamane, K., Kobayashi, K. 2024. Annual production trends of traditional Japanese condiments wasabi. Horticultural Research (Japan), 23(3):213-223. (In Japanese with an English abstract).

# Silvicultural and Ecological Effects of Machine Use in Forestry

**Sena Yavruoglu*, Zafer Yücesan**

Karadeniz Technical University, Faculty of Forestry, Trabzon, Türkiye
*senayavruoglu@gmail.com

## Abstract

Today, the widespread use of machinery in forestry activities has significant impacts on silvicultural practices and ecosystems. This study aims to examine the impacts of machinery used in the forestry sector on forest management, biodiversity and ecosystem health. The use of machinery increases the efficiency of forestry operations, reduces the need for human labour and reduces costs. However, besides these advantages, there are also various silvicultural and ecological impacts. From a silvicultural point of view, operations such as logging, tillage and planting carried out by machines may cause changes in forest structure and dynamics. This can affect the regeneration process of forests, the composition of tree species and the success of rejuvenation efforts. From an ecological point of view, damage to the forest floor by machinery can lead to problems such as soil compaction and erosion. Furthermore, negative impacts on biodiversity can occur during machining operations. For example, habitat fragmentation, shrinkage of wildlife habitats and decline in the populations of some species may occur. In this study, the silvicultural and ecological effects of the use of machinery in forestry will be discussed in detail together with the existing literature. Furthermore, recommendations for sustainable forestry practices will be presented and strategies for minimising these impacts will be discussed. The aim is to provide a perspective on how to maximise the benefits of machinery use in forestry while minimising its environmental impacts.

***Keywords:*** *Mechanisation in forestry, silvicultural practices, sustainable forestry, ecological and biological effects*

## 1. Introduction

The forestry sector is of great importance for the management and conservation of the world's natural resources. As the world's population and industrial demands increase, so does the demand for wood and other forest products. In this context, the integration of mechanisation to increase productivity and reduce costs in forestry activities has become an indispensable element of modern forestry (Pentek, 2005; Sabo and Poršinsky, 2005). However, this technological progress has brought with it several environmental and silvicultural challenges. These challenges are emerging as critical elements that need to be considered for the sustainable management of forest ecosystems.

The integration of mechanisation into forestry practices offers significant advantages in basic forestry activities such as felling, clearing, soil preparation and planting. Machines speed up these processes, reduce the need for labour and provide significant economic savings (Spinelli & Visser, 2008). However, the impact of machine use on forest ecosystems is widely discussed in the literature.
Soil compaction is one of the main negative impacts on forest ecosystems. Compacted soils negatively affect the infiltration capacity of the soil, increasing the risk of erosion and

disrupting the hydrological cycle (Jansson and Johansson, 1998). Young forests in particular can be severely affected by this situation through effects such as restricted root growth and reduced water-holding capacity of the soil (Löf et al., 2012).

The impact of mechanisation on ecosystems is not limited to soil compaction. For example, the fact that machinery reduces the water-holding capacity of the soil also has a negative impact on the hydrological cycle of forests. This can make forests more vulnerable to various environmental threats, particularly drought, due to the changing water balance caused by climate change, increased water stress and the threat of drought (Berger et al., 2013).

Various studies have also reported that machine use can cause habitat fragmentation and degradation of natural ecosystems in forest areas (Smith et al., 2019). Habitat fragmentation threatens the habitats of various forest species and reduces biodiversity (Franklin and Forman, 1987).

In recent years, efforts to develop more environmentally friendly technologies and practices have increased in order to improve the environmental sustainability of forestry activities (Stupak et al., 2007). In addition, the use of light machinery has less environmental impact compared to traditional heavy machinery, which contributes to the protection of forest ecosystems (Öztürk & Şentürk, 2021).

Although the increasing role of mechanisation in forestry activities has led to significant progress in terms of productivity and economic benefits in the sector, it has also created new challenges that need to be considered in terms of sustainable management of forest ecosystems. Therefore, the environmental and ecological impacts of machine use need to be rigorously assessed in order to achieve sustainable forestry objectives. The existing literature highlights the importance of further research in this area and the development of innovative solutions to minimise the environmental impact of forestry practices.

This study aims to contribute to the development of sustainable forestry practices by investigating the silvicultural and environmental impacts of machine use in forestry. A comprehensive analysis of the effects of mechanisation on forestry practices will help to ensure that the decisions to be taken in this area are based on an approach that takes into account the environmental and economic balance.

## 2. Silvicultural and Environmental Impacts of Machinery Use in Forestry

Increasing mechanisation in the forest sector increases the productivity of forestry activities, which in turn has a significant impact on forest ecosystems and biodiversity. The effects of the use of machinery on forest management, biodiversity and ecosystem health have been the subject of increasing research interest in recent years (Let's support with literature).

Although the use of mechanisation in forestry activities increases productivity and reduces labour costs in forest management, it has serious negative impacts on silvicultural practices. As widely discussed in the literature, the use of machinery in forestry activities accelerates forestry operations and provides economic benefits (Ali et al., 2021; Smith et al., 2019). However, in addition to these benefits, activities such as felling, tillage and planting carried out by machinery can negatively affect the structural and functional dynamics of forest ecosystems.

In terms of silvicultural practices, the physical pressure of machinery on the forest floor can lead to significant changes in soil structure. Grafe et al. (2020) emphasise that the physical damage caused by machinery on the forest floor can lead to soil compaction and erosion, which negatively affects the natural regeneration processes of forests. Soil compaction can inhibit root development, especially in young forests, which can threaten the long-term sustainability of forests.

Silva and Lopes (2022) studied the impact of machine use on tree species composition and found that regeneration rates of some species may decrease under this pressure. This is a risk that could negatively affect the biodiversity and ecological resilience of forests.

Silvicultural and ecological impacts are not limited to soil compaction and changes in species composition. Nunes et al. (2018) state that machinery used in forestry reduces the water-holding capacity of the soil and negatively affects the hydrological cycle. Therefore, it is an important parameter to consider in terms of regulating forest-water relations within functional planning strategies, especially in the current context of increasing pressure on water resources due to climate change. Reduced soil water-holding capacity may make forests more vulnerable to drought stress.

Working the forest floor with heavy machinery leads to soil compaction and loss of porosity, which negatively affects the physical properties of the soil. This degradation limits the absorption of water by the soil (infiltration), increasing the risk of soil erosion and leading to a decrease in water resources (Özkan et al., 2017). In addition, such degradation of the natural structure of the forest ecosystem can have serious ecological consequences, such as a decrease in biodiversity and disruption of the ecosystem balance. Öztürk and Şentürk (2021) state that hand cranes used in forests provide a more sustainable alternative to traditional methods by causing less environmental impact. The use of machinery in forestry activities is also an important topic of discussion in terms of environmental sustainability. Oluç and Güzel (2022) examine the environmental impacts of forestry activities and emphasise that these activities can lead to air, water and soil pollution. In this context, it is necessary to develop lighter and more environmentally friendly alternatives to reduce the environmental impact of machinery used in forestry. In addition, the use of new technologies such as unmanned aerial vehicles (UAVs) allows better management of environmental impacts by improving data collection and monitoring processes in forestry activities (Turgut et al., 2022). Scott and Mitchell (2021) considered the impact of the use of machinery in forestry on the biophysical processes of forest ecosystems and highlighted the negative consequences of this impact on the ecological balance and biodiversity of forests.

In a study on the damage that forest road construction can cause to the ecological balance in high slope terrain, machine types such as bulldozer and excavator were used in selected sample areas, and it was concluded that the use of environmentally friendly techniques is much more effective than the use of conventional bulldozers (Melemez, 2004; Tunay and Melemez, 2004).

It was reported that the area of forest opened by the excavator was 26.54% less than the area opened by the dozer; the excess material thrown down the slope during construction caused 55% damage to trees under the road route by the dozer and 31% damage by the excavator. After the road construction was completed, it was noted that the appearance of the embankment slope and materials such as stones were rolled down the road, causing visual deterioration; in addition, this material destroyed the vegetation along the road (Melemez, 2004; Tunay and Melemez, 2004).

Naghdi et al. (2015), in their study on soil damage caused by different felling methods and tools in mountain forests, found that among the different felling techniques, 70.3% of the production area was damaged when felling with a crawler plough, 76.6% of the production area was damaged when felling with a Timberjack 450 C plough, and 87.1% of the production area was damaged when felling with a TAF E655 plough. They concluded that porosity in the surface layer (0-10 cm) decreases with increasing number of passes and increases with increasing slope; therefore, equipment type, number of passes (traffic density) and slope have important effects on soil physical properties.

From a silvicultural and environmental perspective, the use of machinery in forestry has a number of impacts that both serve short-term production goals and threaten long-term ecosystem health. It is therefore important to carefully assess the environmental and ecological impacts of machinery use for sustainable forestry and to develop strategies to minimise these impacts.

**3. Results and Recommendations**

The use of lighter machinery should be encouraged to minimise the negative ecosystem effects of soil compaction caused by machinery on the forest floor. Lighter machines can minimise the negative effects on soil infiltration capacity and plant root development by disturbing the physical structure of the soil less. In addition, to reduce the risk of soil compaction, forest roads and work areas should be regularly inspected and improved where necessary.

To reduce pressure on forest ecosystems, environmentally friendly alternatives to machinery used in forestry operations should be developed. Machines that consume less fuel, have low emissions and minimise soil disturbance will play an important role in protecting forest ecosystems. In this context, the adaptation and use of new technologies in the sector should be encouraged.

In order to minimise the negative impact of machinery in forest areas, appropriate cutting techniques and clearing equipment should be widely used. The techniques to be regulated, depending on the type of management and stand establishment, contribute to the preservation of the natural structure of forests by minimising soil degradation and damage to non-target trees. The use of these techniques is also important for the long-term sustainability of forestry activities.

The use of unmanned aerial vehicles (UAVs) should be increased to improve data collection and monitoring processes in forestry activities. UAVs allow fast and effective monitoring of large areas, enabling better management of environmental impacts. They can also help protect ecosystems by enabling rapid intervention in emergencies such as forest fires.

There is a need to educate and raise awareness among forestry workers about the impact of machinery on ecosystems. In this way, sustainable forestry practices can be implemented more effectively. Training programmes should include strategies to minimise the environmental impact of forestry activities.

In order to develop innovative solutions and sustainable technologies in the sector, more resources should be allocated to research and development (R&D) activities. In particular, efforts to minimise the impact of mechanisation on forest ecosystems should be supported and cooperation in this area should be encouraged. Policies and regulations governing the use of machinery in the forestry sector should be revised to give priority to environmental sustainability.

**References**

Ali, M., Khan, S., Ahmad, N. 2021. Impact of mechanization on forest management efficiency: A comparative analysis. Journal of Forestry Research, 32(4): 655-667. https://doi.org/10.1007/s11676-020-01175-9.

Berger, A.L., Palik, B., Zenner, E.K. 2013. Effects of climatic variability on drought in forests. Forest Ecology and Management, 289: 249-257. https://doi.org/10.1016/j.foreco.2012.10.021.

Franklin, J.F., Forman, R.T.T. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. Landscape Ecology, 1(1): 5-18. https://doi.org/10.1007/BF02275261.

Gräfe, S., Müller, M., Dieter, M. 2020. Soil compaction and erosion risks associated with forest machinery operations: A review of potential impacts on forest ecosystems. Ecological Indicators, 115, 106387. https://doi.org/10.1016/j.ecolind.2020.106387.

Jansson, M., Johansson, M. 1998. Soil compaction due to forestry machinery: Implications for water infiltration and surface runoff. Forest Ecology and Management, 104(1-3): 135-142. https://doi.org/10.1016/S0378-1127(97)00224-9.

Kozlowski, T. T., Pallardy, S. G. 1997. Physiology of woody plants. Academic Press.

Lindenmayer, D.B., Franklin, J.F. 2002. Conserving forest biodiversity: A comprehensive multiscaled approach. Island Press.

Löf, M., Dey, D.C., Navarro, R.M., Jacobs, D.F. 2012. Mechanical site preparation for forest restoration. New Forests, 43: 825-848. https://doi.org/10.1007/s11056-012-9332-x.

Naghdi, R., Solgi, A., Zenner, E.K. 2015. Effects of different ground-based skidding systems on soil compaction in the Hyrcanian forest. International Journal of Forest Engineering, 26(1): 1-11. https://doi.org/10.1080/14942119.2015.1033194.

Nunes, A.N., de Almeida, A.C., Coelho, C.O.A. 2018. Impacts of mechanized forest operations on soil erosion in eucalypt plantations. Land Degradation & Development, 29(8): 2675-2684. https://doi.org/10.1002/ldr.3064.

Oliver, C.D., Larson, B.C. 1996. Forest stand dynamics. Wiley.

Oluç, İ., Güzel, İ. 2022. The relationship between financial globalization and the environment: The case of Turkey. Pamukkale University Journal of Social Sciences Institute. https://doi.org/10.30794/pausbed.1056235.

Özkan, A., Inaç, S. 2017. Review on rehabilitation of burning areas and fire-resistant forests project in Karaisalı Forest Management Directorate. Turkish Journal of Forest Science, 1(1): 59-74. https://doi.org/10.32328/turkjforsci.299976.

Öztürk, T., Şentürk, N. 2021. Sustainable forestry practices using light machinery. Turkish Journal of Forestry, 22(1), 55-66. https://doi.org/10.31197/journalofforestry.12345.

Pentek, T. 2005. Mechanization in forest operations and its environmental implications. Croatian Journal of Forest Engineering, 26(1): 27-35.

Sabo, A., Poršinsky, T. 2005. The influence of mechanized logging operations on the environment in Croatian forestry. Ecological Engineering, 24(1-2): 141-149. https://doi.org/10.1016/j.ecoleng.2004.08.010.

Scott, D., Mitchell, J. 2021. The effects of mechanization on forest biodiversity and ecosystem services. Forest Ecology and Management, 482: 118791. https://doi.org/10.1016/j.foreco.2020.118791.

Silva, L.F., Lopes, J.P. 2022. The effects of forest machinery on tree species composition and regeneration: Insights from tropical forest management. Forest Ecology and Management, 505, 119945. https://doi.org/10.1016/j.foreco.2021.119945.

Smith, J., Brown, A., Thomas, K. 2019. Mechanization in forestry: Impacts on labor and environmental sustainability. International Journal of Forestry and Environmental Studies, 45(2): 230-248. https://doi.org/10.1080/123456789.2019.1234567.

Smith, J.W., Weir, J.R., Scasta, J.D. 2019. Evaluating the effects of forest machinery on habitat fragmentation and ecosystem services. Forest Science, 65(2): 201-210. https://doi.org/10.1093/forsci/fxy055.

Spinelli, R., Visser, R. 2008. Analyzing the impact of mechanization on the cost of forestry operations. Journal of Forest Economics, 14(2): 153-162. https://doi.org/10.1016/j.jfe.2007.12.003.

Stupak, I., Asikainen, A., Jonsell, M., Karltun, E., Lunnan, A., Mizaraite, D., ... Pasanen, K. 2007. Sustainable utilization of forest biomass for energy—Possibilities and constraints. Biomass and Bioenergy, 31(10), 666-684. https://doi.org/10.1016/j.biombioe.2007.06.012.

Turğut, M., Şeker, B. 2022. An exploratory study on the use of unmanned aerial vehicles (UAVs) in transportation: Drone transportation and applications. Journal of Intelligent Transportation Systems and Applications, 5(2): 169-187. https://doi.org/10.51513/jitsa.1146992.

Tunay, M., Melemez, K. 2004. Environmental impacts of forest road construction: A comparative study of bulldozer and excavator use. International Journal of Forest Engineering, 15(2): 31-40. https://doi.org/10.1080/14942119.2004.10702483.

# Detection of Temporal Change in Forest Road Construction Areas with Satellite Imaginary

**Anil Azizoglu*, Erhan Caliskan, Gizem Misirlioglu**

Karadeniz Technical University, Faculty of Forestry, Trabzon, Türkiye
*anlazzoglu@hotmail.com

## Abstract

Forest roads, which are the basic infrastructure facilities of forestry activities, are used throughout the year for transportation and production vehicles to perform forestry services and, most importantly, to open forests for operation. During the construction of forest roads, the main objective is to plan the road routes closest to nature. However, since the construction of forest roads is a direct intervention in nature, it brings with it inevitable damage to nature. In order to detect these damages, this study aims to detect the changes in forest roads using satellite images. Forest roads within the borders of the Forest Management Directorate of Trabzon Forestry Regional Directorate were selected as the study area. It was tried to determine the degree of change that the identified forest roads had an impact on the forest area over time depending on the years of construction. Controlled classification was performed using SNAP software on Sentinel-2 satellite images of 2016, 2019, 2022 and 2024 to determine the current situation. As a result of this study, the time-dependent change of forest road constructions and their damages to the underlying stands were calculated proportionally. It is thought that the resulting data will show the dynamics of forest road changes and provide a basis for future planning.

***Keywords:*** *Forest roads, satellite images, classification, environmental damages, temporal change*

## 1. Introduction

Forest road construction is critical for the sustainable management of forest ecosystems. This process is necessary both for the conservation of natural resources and for providing access to forest areas. Soil transport during the construction of forest roads is an important factor determining the environmental impacts of construction. Soil transport occurs as a direct consequence of construction activities and can affect environmental parameters such as soil quality, erosion and water flow (Acar, 2015; Gülci et al., 2021; Turk et al., 2022).

The management of soil transport during the construction of forest roads should be considered at the planning stage of construction. Accurate assessment of topographic data, optimisation of soil movements, and balance between filling and excavation are essential for the success of this process (Gülci et al., 2021; Turk et al., 2022). In addition, the use of modern technologies such as unmanned aerial vehicles (UAVs) allows for more precise soil transport and volume calculations (Turk et al., 2022; Kinali and Çalişkan, 2022). Such technologies help to minimise environmental impacts while saving time and cost during the construction process. The relationship between forest roads and satellite imagery is an important issue in forest management, natural disaster response strategies and environmental monitoring. Remote sensing technologies provide an effective tool for monitoring the condition of forest roads and environmental changes (Demir, 2023). Satellite images are also used to monitor the condition of forest roads and ecosystem changes around them. For example, Güverçin and Günlü conducted studies to estimate forest biomass using different satellite images (Güverçin and Günlü, 2023).

The impacts of soil transport are not only limited to the construction process, but can also have significant consequences on the health of the forest ecosystem in the long term. Improperly managed soil transport can increase the risk of erosion, which can lead to pollution of water resources (Acar, 2015). Therefore, effective management of soil transport in forest road construction is of vital importance for both environmental sustainability and protection of forest resources. Soil transport during forest road construction is a complex process that requires careful planning and management. In this process, integration of modern technologies and consideration of environmental impacts play a critical role for sustainable forest management (Acar, 2015; Turk et al., 2022; Kinali and Çalişkan, 2022).

In this study, the temporal variations of soil transport during the construction of forest roads were analysed. In order to determine the effects of forest roads on forest areas, controlled classification method was applied using SNAP 10.0.0 software. This method made it possible to determine the effects of forest roads on forest ecosystems in different time periods more precisely. In addition, in the light of the data obtained, the effects of temporal changes of forest roads on forest areas were evaluated. This study aims to contribute to the development of sustainable forestry practices by revealing the long-term environmental impacts of forest road construction processes.

## 2. Materials and Methods

In this study, the effect of the forest road, which was started to be constructed in 2019 and completed in 2021 in Tonya Forest Management Directorate within the borders of Trabzon Regional Directorate of Forestry, on the forest area was analysed (Figure 1).

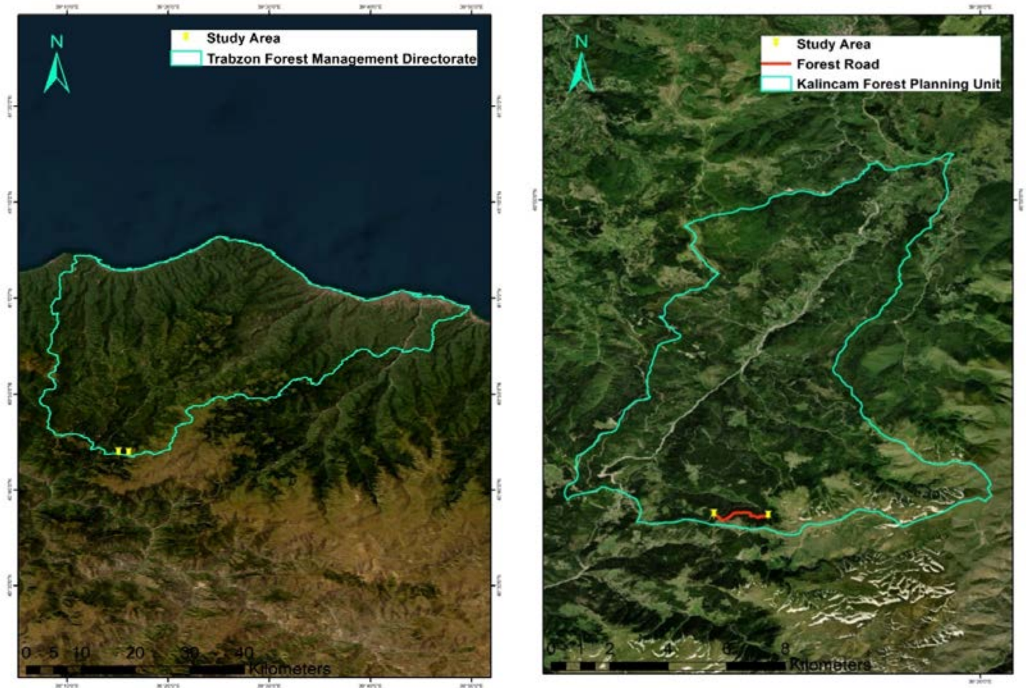



Figure 1. Study Area

The average altitude of Kalıncam region is 700 metres and the region is generally covered with mountainous areas. Forested areas are common in these areas. The forests in the region are home to tree species such as Red Pine (Pinus brutia Ten.), Cedar (Cedrus libani), Sycamore (Platanus orientalis), Larch (Pinus nigra) and Juniper (Juniperus spp.) at altitudes ranging from 700 metres to 1200 metres. In the study process, controlled classification method was applied using SNAP software on Sentinel-2 satellite images of 2016, 2019, 2021 and 2023. The change in forest areas over the period was revealed on the maps created.

Sentinel Application Platform (SNAP) is an open source software developed by the European Space Agency (ESA), specifically designed for the processing and analysis of data from Sentinel satellites. SNAP provides a modular structure for processing optical, radar and multi-spectral data from different satellite missions such as Sentinel-1, Sentinel-2 and Sentinel-3, and is also compatible with other satellite data formats. The software includes advanced image processing algorithms such as spectral analysis, classification, interferometry and topographic analysis, and is widely used in the visualisation and analysis of remote sensing data in scientific research (Figure 2).

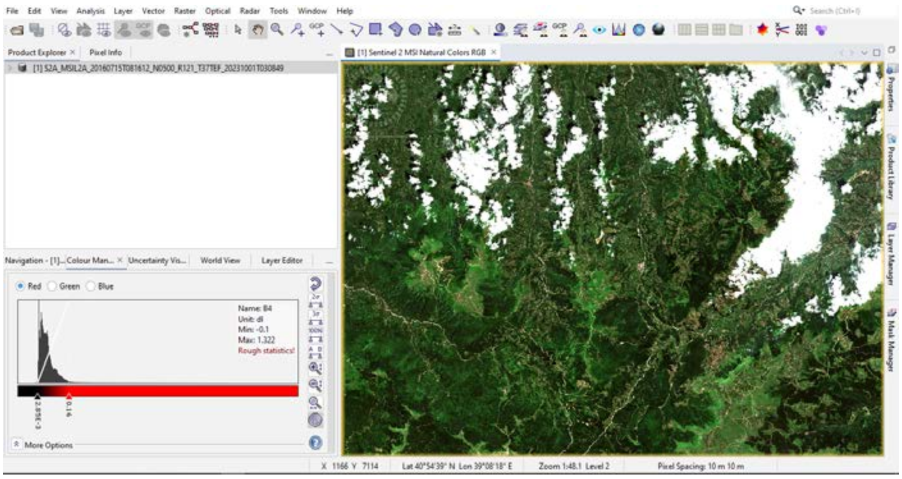


Figure 2. Snap Software

In this study, satellite images of the Sentinel-2 (MSI) satellite provided by the European Space Agency (ESA) for the years 2016, 2019, 2021 and 2023 are used. The bands, spectral information and resolution details of Sentinel-2 satellite are presented. Various band combinations can be applied for visual interpretation of satellite images and to distinguish burning areas from other areas. In this study, the three most commonly used band combinations were preferred. (B4 (Red) - B3 (Green) - B2 (Blue)) band combination was used in Sentinel-2 images.

Controlled classification on Sentinel Application Platform (SNAP) is an analysis method for distinguishing different land cover types in satellite imagery based on user-specified sample areas. In SNAP, classification is performed through selected sample pixels on spectral bands and the results can be exported as a classified map, enabling effective analysis of different land covers with remote sensing data. In this study, land cover changes were analysed by applying controlled classification method to Sentinel-2 satellite data for the years 2016, 2019, 2021 and 2023 through SNAP software. Different control plots were created for the classes required in the controlled classification process (forest roads, forest area, bare land) (Figure 3, 4, 5, 6).

Figure 3. Representation of control parcels on Sentinel-2 satellite image of 2016 (green: forest area, yellow: bare land, red: forest road)

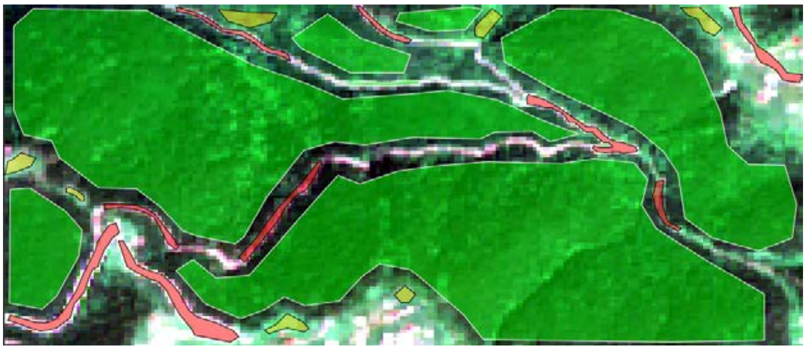


Figure 4. Representation of control parcels on Sentinel-2 satellite image of 2019 (green: forest area, yellow: bare land, red: forest road)

Figure 5. Representation of control parcels on Sentinel-2 satellite image of 2021 (green: forest area, yellow: bare land, red: forest road)

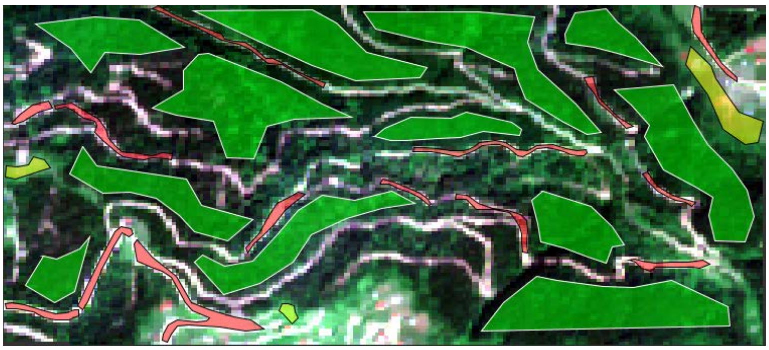


Figure 6. Representation of control parcels on Sentinel-2 satellite image of 2023 (green: forest area, yellow: bare land, red: forest road)

After the controlled classification process performed on SENTINEL-2 satellite images between 2016-2023, the changes in forest areas were analysed. In line with the findings obtained, analyses were made on the observed changes and comments were made on the potential effects of these changes on forest ecosystems.

## 3. Results and Discussion

In 2016, as a result of the controlled classification process on satellite images, forested area was determined as 84.50%, bare land 8.86% and forest road 6.58% (Figure 7). In 2019, as a result of the controlled classification process on satellite images, forested area was determined as 83.02%, bare land as 6.56% and forest road as 10.41% (Figure 8).

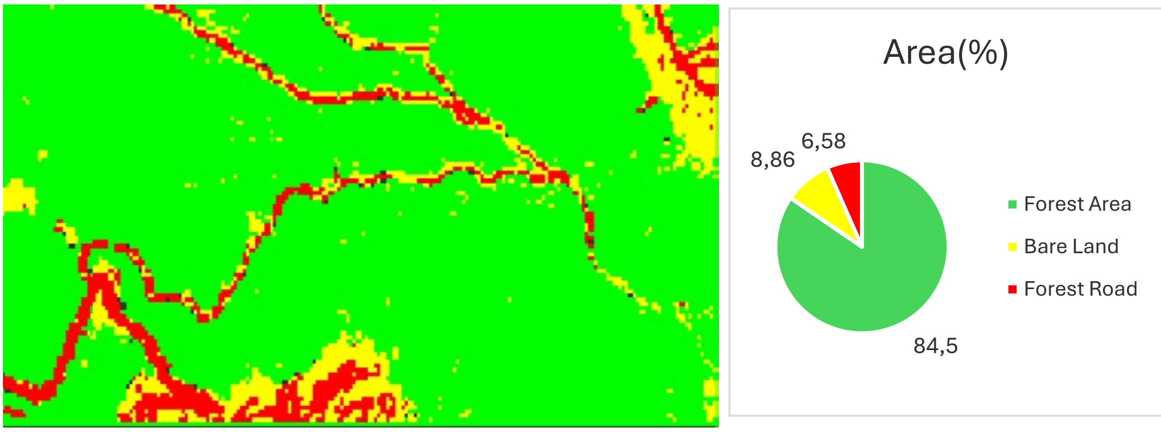



Figure 7. Controlled classification results for 2016

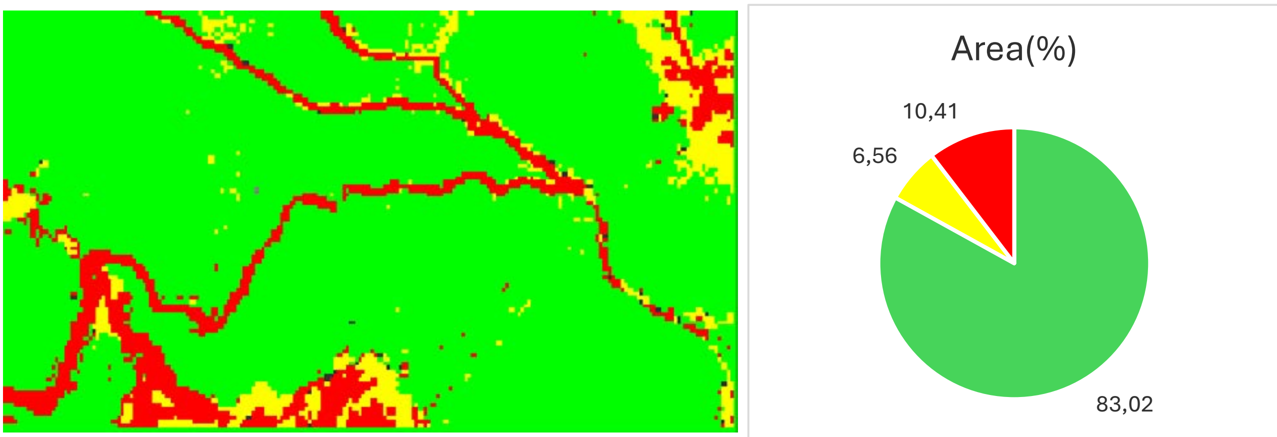



Figure 8. Controlled classification results for 2019

As a result of the 2021 controlled classification process on satellite images, forest area was determined as 75.83%, bare land 8.91% and forest road 15.25% (Figure 9). As a result of the controlled classification process on 2023 satellite images, forest area was determined as 71.83%, bare land as 9.96% and forest road as 18.20% (Figure 10).

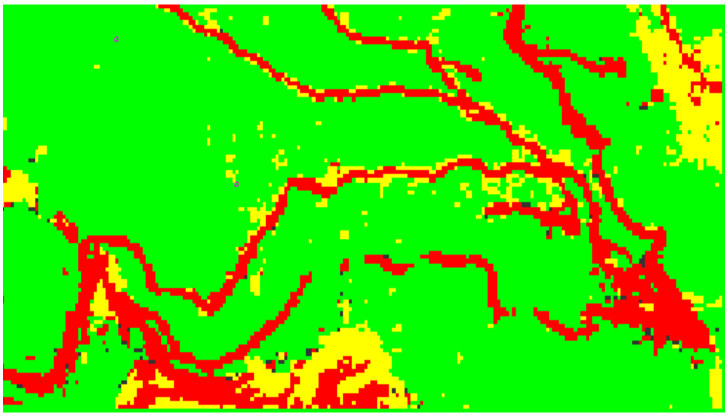
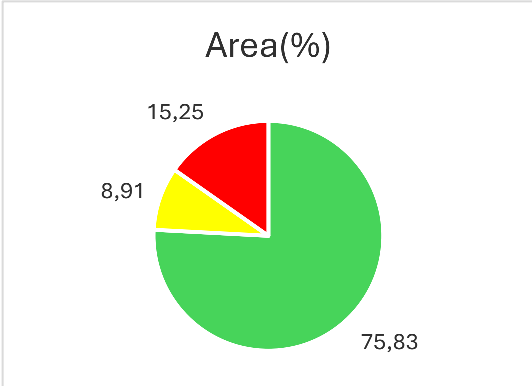




Figure 9. Controlled classification results for 2021

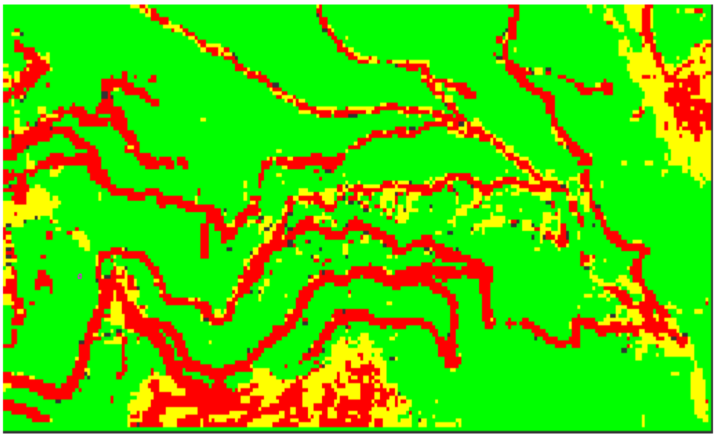
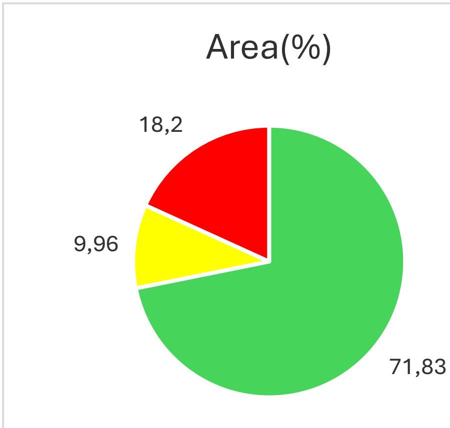




Figure 10. Controlled classification results for 2021

According to the results of the analyses, forest areas have shown a continuously decreasing trend between 2016 and 2023. This situation can be interpreted as deforestation or conversion of forests to other uses (Table 1).

Table 1. Areal changes between 2016-2023

| | 2016 (%) | 2019 (%) | 2021 (%) | 2023 (%) |
|---|---|---|---|---|
| Forest Area | 84.50 | 83.02 | 75.83 | 71.83 |
| Bare Land | 8.86 | 6.56 | 8.91 | 9.96 |
| Forest Road | 6.58 | 10.41 | 15.25 | 18.20 |

When the percentage analysis of areal changes by years is analysed, it is determined that forest areas decreased by 14.99% between 2016-2023. In the same period, the change in bare lands fluctuated in the form of increases and decreases. When forest roads are evaluated, unlike the decrease in forest areas, an increase of 11.62% was observed in the area values of these roads. The observations reveal that there is an inversely proportional relationship between forest roads and forest areas. The observed increase in forest roads resulted in a significant decrease in forest areas. Analyses performed on satellite images of the selected region show that this change indicates that forest roads may lead to the loss or fragmentation of forest areas.

The loss of forested areas poses serious problems for environmental and ecosystem balance and is directly related to the construction and utilisation of forest roads. Forest roads are critical for the conduct of forestry activities, and their planning and construction requires great care both economically and environmentally. It is emphasised that determining the most appropriate routes of forest roads in the natural environment is of vital importance for forest management (Acar, 2015). While these roads facilitate access to forest areas, they can also threaten the integrity of forest ecosystems.

The use of modern technologies such as remote sensing and geographic information systems (GIS) has become an important tool for monitoring and detecting the loss of forest areas (Yüksel, 2022). These technologies are critical for assessing the impacts of forest roads and developing strategies to minimise the loss of forest areas. Furthermore, sustainable forest management practices are an important element to be considered in the planning and construction of forest roads (Akyol & Tolunay, 2014). In this study, the changes in forest areas and forest roads were observed by using Sentinel-2 satellite images with SNAP 10.0.0 software, and as a result of the study, it can be said that there is a connection between the decrease in forest areas and forest roads.

**4.Conclusion and Suggestions**

This study analysed the impacts of forest road construction on forest ecosystems and assessed environmental changes, particularly soil transport and forest area reduction, using satellite imagery. Analyses of Sentinel-2 satellite imagery between 2016 and 2023 during the study period showed a significant decrease in forested areas and a significant increase in forest roads. The area of forest roads increased from 6.58 per cent to 18.20 per cent, while forest areas decreased from 84.5 per cent to 71.83 per cent. These findings reveal that improperly planned forest road constructions that are not integrated with nature directly lead to deforestation and soil loss, which threatens the integrity of forest ecosystems.

Although forest roads have a critical importance for forestry activities, improper planning and management of these roads have negative impacts on ecosystem balance. Analyses show that there is an inverse relationship between the construction of forest roads and the decrease in forest areas. This indicates that if environmental impacts are ignored during the construction of forest roads, sustainable forestry practices may be jeopardised in the long term.

Consequently, in order to minimise the environmental impacts of forest road construction, road routes should be carefully planned, and their environmental impacts should be assessed in detail prior to construction. Integration of modern technologies, especially remote sensing and geographic information systems (GIS) can play a critical role in environmental monitoring and assessment processes. In addition, developing strategies in accordance with sustainable forestry principles and training all employees involved in forest road construction on environmental impacts are important to minimise the negative impacts of these processes on nature and to ensure the protection of forest ecosystems.

**References**

Acar, H. 2015. Environmental sensitive road planning and transportation techniques in forest engineering. İstanbul Üniversitesi Orman Fakültesi Dergisi, 66(2). https://doi.org/10.17099/jffiu.79204

Akyol, A. and Tolunay, A. 2014. Sürdürülebilir orman yönetimi ölçüt ve göstergelerinin türkiye için modellenmesi. Turkish Journal of Forestry | Türkiye Ormancılık Dergisi, 15(1): 21. https://doi.org/10.18182/tjf.15028

Demir, S. 2023. Google Earth Engine üzerinde Sentinel-2 uydu görüntüleri kullanılarak yanan alanların farklı eşik değerlerinde belirlenmesi. Türk Uzaktan Algılama ve CBS Dergisi, 4(2): 262-275.

Gülci, S., Akgül, M., Gülci, N., Demir, M. 2021. Orman yolu güzergahlarının belirlenmesinde farklı tekniklerle üretilmiş sayısal arazi modellerinin kullanılması üzerine bir araştırma. Bartın Orman Fakültesi Dergisi, 23(2): 654-667. https://doi.org/10.24011/barofd.908019

Güverçin, İ., Günlü, A. 2023. Saf Kızılçam (Pinus brutia Ten.) Meşcerelerinde Aktif ve Pasif Uydu Görüntüleri Kullanılarak Topraküstü Biyokütlenin Tahmin Edilmesi (Anamur Orman İşletme Şefliği Örneği). Bartın Orman Fakültesi Dergisi, 25(1): 177-191.

Kinali, M., Çalışkan, E. 2022. İnsansız hava araçlarının orman yolu projelerinde kullanımı. Bartın Orman Fakültesi Dergisi, 24(3): 530-541. https://doi.org/10.24011/barofd.1073229

Turk, Y., Canyurt, H., Eker, R., Aydın, A. 2022. İnsansız hava aracı ile orman yolu kazı ve dolgu hacimlerinin belirlenmesi: bolu-taşlıyayla örneği. Ormancılık Araştırma Dergisi, 9(Özel Sayı): 97-104. https://doi.org/10.17568/ogmoad.1093695

Yüksel, K. 2022. Evaluation of different remote sensing indices in detection of forest burned area: a case study of 2022 mersin (gülnar) wildfire. Artgrid - Journal of Architecture Engineering and Fine Arts, 4(2): 160-171. https://doi.org/10.57165/artgrid.1179074

# Determining the Effects of Logging Process on Forest Cover Using Geographic Information Systems and UAV

**Gizem Misirlioglu*, Selcuk Gumus, Taha Yasin Hatay**

Karadeniz Technical University, Department of Forest Engineering, Faculty of Forestry, Trabzon, Türkiye
*gizemyorulmaz@ktu.edu.tr

## Abstract

Today, with the increasing demand for forest products, forest areas are being used more and more intensively. This use also brings environmental damage. In recent years, with people who want to escape from cities turning to natural environments, the prevention and detection of environmental damages of all kinds of activities that interfere with nature has become more important. It is known that the stage with the most interventions in forest management is the logging process. For this reason, in this study, the damages of logging activities in the remaining stand in the area within the boundaries of Borcka Forest Management Directorate of Artvin Regional Forest Directorate were studied. For this purpose, unmanned aerial vehicle (UAV) images, satellite images from the past years and the present were analyzed. Images of the compartment before and after the logging process were obtained with the UAV. Analyses will be made on these images to determine the change of the compartment and its effects on the surrounding stands. Through satellite images, NDVI analysis will be made on the before and after situation and the effects of the logging process on the environment will be determined. As a result of these analyzes, it is aimed to determine the effects of the logging process on forest cover with remote sensing methods.

***Keywords:*** *Logging, stand damage, satellite images, UAV, GIS*

## 1. Introduction

Forests are natural and renewable resources that provide goods and services to meet the needs of society. The forestry sector not only provides wood raw materials, but also plays an important role in the protection of natural life and the maintenance of biodiversity. In this sector, there is a management of a biological asset that is open to natural conditions and dependent on land (Acar and Ünver, 2004). In order to protect this biological asset and ensure its sustainability, logging activities and forest constructions should be planned in an environmentally sensitive manner.

The logging process is an important area in terms of its environmental impacts, and practices in this process can have significant consequences on both ecosystems and human health. Logging leads to various environmental problems such as the use of natural resources, loss of biodiversity and reduction of ecosystem services. In this context, the adoption of sustainable practices is critical for reducing environmental impacts (Değirmenci, 2023).

Among the most important environmental impacts of the overland transportation of wood raw material are soil compaction and landslides. This has been shown to reduce soil porosity in the forest floor, affecting water infiltration, soil moisture, soil aeration and root volume (Greacen and Sands, 1980).

Determining the environmental damages of logging operations is of increasing importance today. In this context, environmental impact assessments using unmanned aerial vehicles (UAVs) have emerged as an important tool for monitoring logging processes and determining their environmental impacts. UAVs can provide detailed information on the state of forest ecosystems thanks to their ability to quickly scan large areas and collect data (Aksoy et al., 2021).

One of the main uses of NDVI, which will also be used in this study, is to monitor soil degradation caused by human activities. For example, Rodrigues et al. (2020) emphasized that human activities such as deforestation and agricultural expansion have led to significant reductions in vegetation cover and leaf area, and that these changes can be effectively monitored by NDVI assessments. Similarly, Júnior et al. (2022) emphasized that NDVI is an important tool for detecting environmental degradation in various ecosystems, underlining its reliability for such assessments in the scientific literature.

In this study, research was conducted on the environmental damages of a clearing work given to forest villagers through a standing sale tender. For this purpose, environmental damages were tried to be determined on unmanned aerial vehicle images taken before and after cutting. In addition, NDVI analysis was performed on Landsat images of 2021 and 2024 for comparison.

## 2. Material and Methods

This study was carried out in the area numbered 363 within the boundaries of Camili Forest Management Chiefdom of Borçka Forest Management Directorate of Artvin Forestry Regional Directorate in Türkiye (Figure 1).

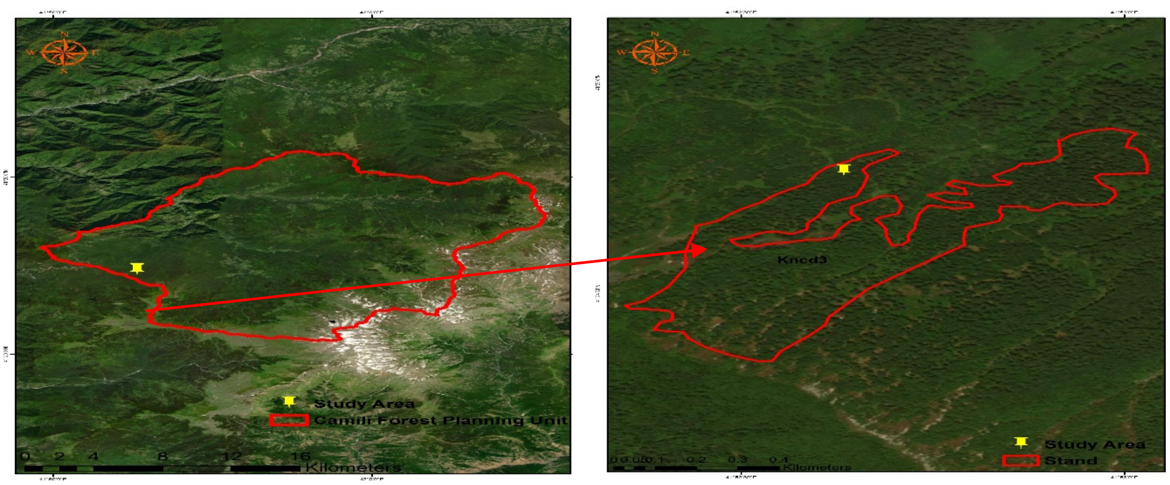



Figure 1. Study area

In this compartment, *Fagus orientalis* L. species formed a pure stand. The stand is in the fine and medium woody stage (cd) and 3 (70-100%) closed stands. Since it has not yet completed its management period, a spacing study was deemed appropriate. Spacing is the first maintenance intervention in the stand after density maintenance. In this process, individuals affecting the future of the stand, i.e. future trees, are removed from the area. Felling operations in this area were tendered to forest villagers by the Forest Management Directorate. The trees to be removed from the area were stamped by OGM personnel and the stand was delivered to the forest villagers (Figure 2).

Figure 2. Condition of the work area before cutting

Skidding trails were opened in the area and extraction was made from these skidding trails by using the crane skidding method (Figures 3 and 4). The logging method was selected as the production method.

Figure 3. Skidding trails

Figure 4. Truck with crane used for harvesting operations

Unmanned aerial vehicle images were used to examine the environmental impacts of the clearing work. For this purpose, images were taken before (June 2023) and after (August 2024) felling. The shots were taken from a height of 30 meters, so that the whole stand could be seen.

Since the study area is between 1700-1800 meters, the area was visited repeatedly in order to capture a clear image. However, since the fog density was high, the post-cutting shots taken in 2024 were taken from a maximum height of 25 meters because the drone could lose its signal and could not be shot (Figure 5).

Figure 5. Fog density in the study area

In addition to the images, NDVI (Landsat Normalized Difference Vegetation Index) analysis was performed on Landsat-8 maps of 2021 and 2024 for the same area. As a result of this analysis, it was tried to determine the change in vegetation before and after cutting. The values obtained as a result of NDVI analysis vary between -1 and +1. Where healthy and dense vegetation cover is high, the index value approaches towards +1, while where unhealthy and weak vegetation cover is high, the index value approaches towards -1. In this study, NDVI values before and after cutting were determined (Figure 6).

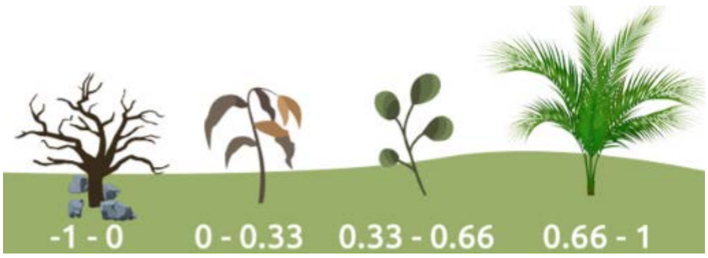



Figure 6. NDVI Scale (URL-2)

## 3. Results and Discussion

This study was carried out in Artvin province, where logging activities are high in Türkiye. In the field, the logging method was used and the method of splitting was used by lifting one side with a crane from the skidding trails. Pre-stamped trees in the area were cut using a chainsaw and sorted into logs within the stand. The logs were dragged to the roadside where they were loaded onto trucks and delivered directly to the buyer.

### 3.1 Measurements with Unmanned Aerial Vehicle

In June 2023, just before the cutting started, the skidding trails were opened and shots were taken from 30 meters with an unmanned aerial vehicle. As a result of these shots, the current closure of the stand is clearly seen (Figure 7). In addition, due to the high elevation of the region, the area is generally under snow cover. For this reason, in some places, the extraction operations were also carried out by plowing on snow (Figure 8).

Figure 7. Stand closure before cutting

Figure 8. Snow cover in the area

The shooting after the cutting was carried out in August 2024. Due to the high fog density in the area, it was possible to shoot from a height of 25 meters. In the images obtained, soil damage in the skidding trails can be clearly seen (Figure 9). The amount of cutting residues left in the field can also be determined (Figure 10). The before and after images clearly show the traces of felling in the stand (Figure 11).

Figure 9. Soil damage in the skidding trail

Figure 10. Cutting residues in the field


Figure 11. A: Before cutting, B: After cutting

The use of UAVs offers a broader perspective on the detection of environmental damage in logging processes. For example, data from UAVs allows for the assessment of impacts on forest health, biodiversity and ecosystem services. Such data can also be used in environmental impact assessments (EIA) processes so that the environmental impacts of logging activities can be better understood (Kuran, 2021).

UAVs have been used effectively especially in the early detection and response processes of forest fires. Aksoy et al. reported successful results in the detection of forest fires by combining UAVs with image processing techniques (Aksoy et al., 2021). Such technologies can be similarly used to monitor environmental changes in logging areas. Furthermore, the data provided by UAVs can be integrated with life cycle assessments (LCA), which are important for environmental sustainability, allowing for a more comprehensive analysis of the environmental impacts of logging processes. However, there is no direct reference on specific applications of LCA to logging processes (Kiliç, 2020). In this context, UAVs can contribute to the development of sustainable logging practices by monitoring changes in forest areas.

### 3.2 NDVI Analysis

In this study, NDVI analysis was also performed for the detection of vegetation in order to compare the results obtained from drone images. For this; Landsat-8 satellite images of 2021 and 2024 were obtained using the Earth Explorer database (URL-1). The obtained images were cropped by taking into account the boundaries of the study area and NDVI analysis was applied. In the study area, NDVI was formed as 3 classes (Turgut and Güler, 2023). These classes 0.23-0.36, 0.36-0.45, 0.45-1 respectively indicate vegetation cover ranging from weak vegetation cover to higher vegetation cover. (Figure 12).

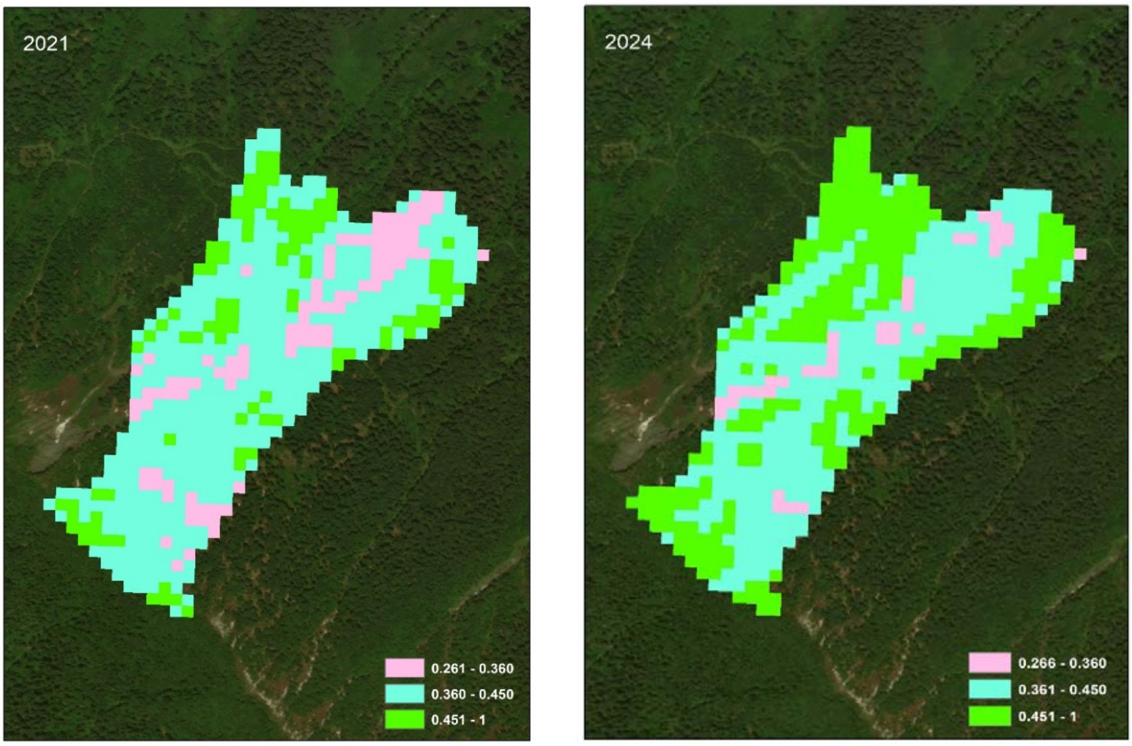



Figure 12. NDVI analysis results

As a result of the analysis, while the NDVI value varies between 0.261446 and 0.497989 in 2021, this value varies between 0.26601 and 0.537477 in 2024. It is expected that the lower value will increase, and the upper value will decrease in this cut area in 2024. Because as the value approaches 1 on the NDVI scale, it means that there is more healthy and dense vegetation. However, because 1 year has passed since the cutting, it is thought that it will not affect the value completely and that the living cover in the stand can grow in 3 years and affect the NDVI value.

## 4. Conclusion and Suggestions

In this study, the change in a cut area was tried to be revealed with unmanned aerial vehicles and NDVI analysis. As a result, it is thought that the images obtained by the unmanned aerial vehicle before and after the cutting clearly indicate the condition of the stand. It is also thought that more effective results can be obtained when more equipped unmanned aerial vehicles are used for measurement-based analysis. The machinery and techniques used in logging also play an important role in determining environmental impacts. The use of modern technologies, such as air lines, increases the efficiency of logging processes and reduces environmental impacts. As a result, the environmental impacts of the logging process are directly related to the methods, tools and sustainability practices used. Reducing environmental impacts requires careful planning, the use of innovative technologies and the adoption of sustainable practices in logging processes. This approach will contribute to both protecting ecosystems and safeguarding human health.

## References

Acar, H. H., Ünver, S. 2004. Odun Hammaddesi Üretiminde Teknik Ve Çevresel Açıdan Zararların Tespiti İle Çözüm Önerileri. Bartın Orman Fakültesi Dergisi, 6(6): 165-173.

Aksoy, B., Korucu, K., Çalışkan, Ö., Osmanbey, Ş., Halis, H. 2021. İnsansız Hava Aracı İle Görüntü İşleme Ve Yapay Zekâ Teknikleri Kullanılarak Yangın Tespiti: Örnek Bir Uygulama. Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 9(6): 112-122. https://doi.org/10.29130/dubited.1016195

Değirmenci, B. 2023. Borsa istanbul 50'de yer alan firmaların kurumsal sosyal sorumluluk faaliyetlerinin çevresel sürdürülebilirlik yönünden incelenmesi. İzmir İktisat Dergisi, 38(2): 375-399. https://doi.org/10.24988/ije.1137871

Greacen, E.L., Sands, R. 1980. Compaction Of Forest Soils: A Review Australia Journal Soil Resource, Australia.

Kiliç, İ. 2020. Estimation of environmental effects of industrial tomato cultivatıon in field by the life cycle assessment method. Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi, 6(2): 287-295. https://doi.org/10.24180/ijaws.722511

Kuran, S. 2021. Türkiye'de gida sanayinde uygulanan çed çalişmalarinin çevresel açidan değerlendirilmesi ve eleştirisi. Mehmet Akif Ersoy Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 8(2): 907-930. https://doi.org/10.30798/makuiibf.836120

Oliveira-Júnior, J., Shah, M., Abbas, A., Correia Filho, W. L. F., Silva Júnior, C., Santiago, D., ... & Aviv-Sharon, E. 2022. Spatiotemporal Analysis of Fire Foci and Environmental Degradation in the Biomes of Northeastern Brazil. Sustainability, 14: 6935.

Rodrigues, J. A. D. M., Lopes, P. M. O., Silva, J. L. B. D., Araújo, H. L., Silva, M. V. D., Santos, A. D., ... & Moura, G. B. D. A. 2020. Spatial-temporal dynamics of Caatinga vegetation cover by remote sensing in the Brazilian semiarid region. Dyna, 87(215): 109-117.

Turgut, B., Güler, S. 2023. "Assessment of soil quality index for different NDVI ranges in a watershed,"*Turkish Journal of Agriculture and Forestry*: Vol. 47: No. 6, Article 7. https://doi.org/10.55730/1300-011X.3134

URL-1. 2024. September 2. https://earthexplorer.usgs.gov/

URL-2 2024. September 2. https://www.usgs.gov/landsat-missions/landsat-normalized-difference-vegetation-index#:~:text=Landsat%20Normalized%20Difference%20 Vegetation%20Index%20(NDVI)%20is%20used%20to%20quantify,assessing%20changes%20in%20plant%20health.

# Passing Ability of Medium-Sized Log Trucks in Mountainous Forest Areas in Japan

**Yasushi Suzuki[1*], Tetsuhiko Yoshimura[2], Hisashi Hasegawa[3], Kazuhiro Aruga[4]
Masashi Saito[5], Kai Moriguchi[6], Hiroaki Shirasawa[7]**

[1]Faculty of Agriculture and Marine Sciences, Kochi University, Nankoku, Japan
[2]Faculty of Life and Environmental Sciences, Shimane University, Matsue, Japan
[3]Field Science Education and Research Center, Kyoto University, Kyoto, Japan
[4]Faculty of Agriculture, Utsunomiya University, Utsunomiya, Japan
[5] Faculty of Agriculture, Iwate University, Morioka, Japan
[6] Faculty of Agriculture, Shinshu University, Ina, Japan
[7]Department of Forest Engineering, Forestry and Forest Products Research Institute, Tsukuba, Japan
*ysuzuki@kochi-u.ac.jp

## Abstract

The size of log transport vehicles has tended to become larger in the world, while it is difficult in mountainous forest areas. There are three types of standard vehicles for both public roads and forest roads in Japan, expressed in terms of payload. These are 4-ton class trucks, 10-ton class trucks, and 20-ton class semitrailers. The corresponding road standards are practically the same as the road width classes expressed in the GIS data: less than 3.0 m, 3.0-5.5 m, and more than 5.5 m. Although officially every public road should be able to accommodate 10-ton class trucks, the steep and complicated terrain in Japan's mountainous forest areas does not allow 10-ton class trucks in a significant portion of the areas. Recently, many carriers have begun to use medium-sized trucks, such as 10-ton short-body trucks and 6-ton reinforced trucks, to transport logs in such difficult terrain areas. In this paper, the passing ability of such medium-size log trucks was investigated in terms of the required road width expansion in relation to curve radius and truck body size. The practical passing ability of the medium-sized trucks is discussed using municipal-level GIS data of the road network in mountainous forest areas in Japan.

***Keywords:*** *Log truck, medium-sized trucks, mountainous forest area, passing ability, standard vehicle size*

## 1. Introduction

The standard forest road vehicles in Japan were two types: "4-t class trucks" and "10-t class trucks," where 4-t and 10-t refer to payload. The sizes of log trucks have been increased in response to the global trend of mass transportation (Kärhä et al., 2024). Recently, also in Japan, "20-t class semitrailer" was added to reduce the cost of log transportation and to meet the growing mass transportation (Figure 1). These three types are the same as those for public roads (Suzuki et al., 2022). The road standard regulates the road width, such as 3.0 m for the 2nd grade forest road as well as the lowest grade public road (Suzuki et al., 2022). Although the standard vehicle width is less than 3.0 m even for a 20-ton class semi-trailer, steep slopes and winding roads in mountainous forest areas in Japan force the road width to be widened for the passage of large trucks (Suzuki et al., 2015). That is, even if wide forest roads for 20-t class semitrailers are constructed for forested areas in the deep ends of public road networks, there would be problems with the ability to pass in such areas (Suzuki et al., 2022).


Figure 1. Three types of standard vehicles on Japanese public and forest roads

Suzuki et al. (2023) investigated six public roads in Kochi Prefecture, Japan, that connect mountainous forest areas to sawmills and lumber yards by checking whether appropriate road width expansion is applied at the center points of curves and found that there are many public roads in mountainous forest areas that are passable only by 4-ton class trucks. They also concluded that three classifications of road width in commercial and open GIS data, i.e., less than 3.0 m, 3.0-5.5 m, greater than 5.5 m, can be treated as passable road widths for 4-ton class trucks, 10-ton class trucks, and 20-ton class semitrailers, respectively (Suzuki et al. 2023; Figure 2).

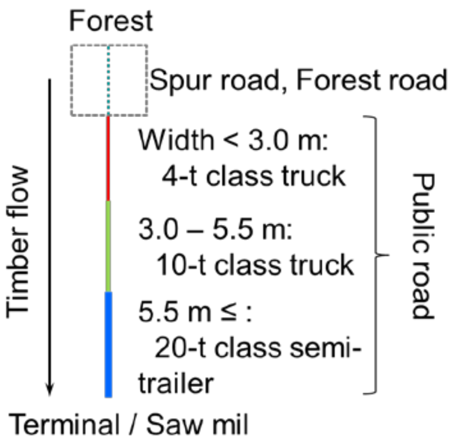



Figure 2. Log transportation from the forest to public roads

In log transportation, the flow of timber begins in a forest compartment. After harvesting, the harvested logs are transported from a landing in the forest compartment on spur and/or forest roads. A log transport route on a public road can start from the closest point on the public road network to the corresponding forest compartment. At this point, the road width is expected to be the narrowest, i.e. less than 3.0 m. In such cases, the first transport should be performed by the smallest vehicle, i.e. a 4-ton class truck. Appropriate widening of the road or changing the mode of transport at an intermediate landing would be possible solutions. However, there may be such directly connected points on a road with larger width. In this case, a 10-ton class truck or a 20-ton class semi-trailer could be used at the first transport point in the forest compartment.

The objective of this paper is to find possible solutions for improving log transport logistics in mountainous forest area. First, the road density in some selected municipal areas is analysed according to road width classes corresponding to standard vehicle types. Then, log transport routes from the forest compartment to target terminals such as sawmills or log stock yards are searched and analysed. Based on the obtained results, the usability of medium trucks is discussed as one of the possible solutions.

## 2. Materials and Methods

The public road network data were obtained from the open GIS data source of the Geospatial Information Authority of Japan. Part of the detailed information was obtained from commercial GIS data provided by Itsumo-NAVI-API service of ZENRIN CO., LTD. through a temporary contract (Suzuki et al., 2023). The analysed areas were mainly selected from Kochi Prefecture in one unit of municipality. Kochi Prefecture is located in the central western part of Japan, one of the four prefectures that make up Shikoku Island. That is, Kami City, Ototyo Town and Ino Town as extremely with steep terrain where long-distance cable systems are often used for logging operation. In Kami City, tower yarders, Japanese-style swing yarders, and small systems such as mini forwarders are also used. Two other municipalities, Niyodogawa Town and Shimanto Town, were also selected, where small-scale systems are mainly used. As for other areas, Iwate Town in Iwate Prefecture, Utsunomiya City and Sano City in Tochigi Prefecture, and Matsue City in Shimane Prefecture were selected. All of them have not so difficult terrain compared to Kochi Prefecture. The road density of the public road was calculated by three road width classes by summing the lengths of the road elements and divided by the area using QGIS software ver. 3.16.9.

In order to examine the public road width class of timber flow at the start points, a route search procedure from forest plots to the destination was conducted. The connecting points on the public road from the plots determine the truck size of the first transport. That is, if the road width of the connecting point is less than 3.0 m, then a 4-ton class truck should be used from the stat point of the timber flow. If it is 3.0-5.5 m, 10-t class trucks can be used. The search was applied for selected each municipality. Two or three targets were set for each municipality. In the search procedure, two objectives were applied: travel distance or travel time, so as to minimize one of them. When the subject parameter is time, vehicle travel time was set to 20, 30, and 40 km/h for road width less than 3.0 m, 3.0-5.5 m, and more than 5.5 m, respectively.

Two municipalities were selected for the study: Kami City and Niyodogawa Town, Kochi Prefecture. The targets for Kami City were two log stock yards. For Niyodogawa town, there were three destinations: a sawmill and two national road points on the border of the municipality, one toward the western neighbouring municipality and the other toward the eastern neighbouring municipality (Figures 3 and 4). Two types of forest compartment data were used in the route search: small compartment and large compartment. In both cases, the route selection was started from a center of gravity of each compartment (Figure 5). From the compartment center, the nearest point in a straight line on the public road network was found, whereas the route will be winding as forest roads or spur roads in actual cases. Then a route on the public road network was searched so that one of the objectives would be minimized: travel distance or travel time on the public road route to each target destination.

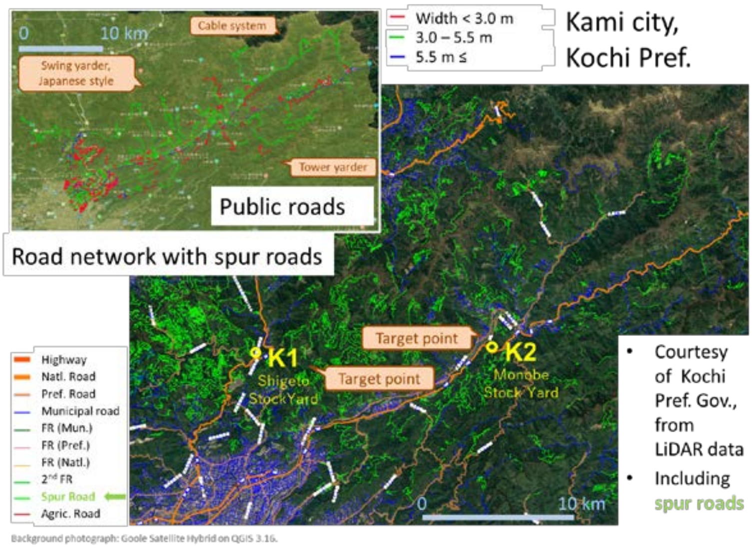



Figure 3. Road distribution and route search destinations in Kami City, Kochi Pref.

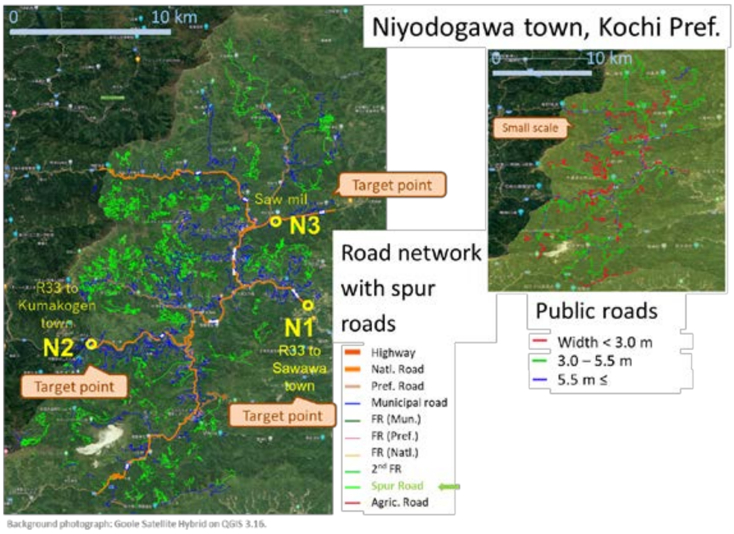



Figure 4. Road distribution and destination points of route search in Niyodogawa Town, Kochi Pref.

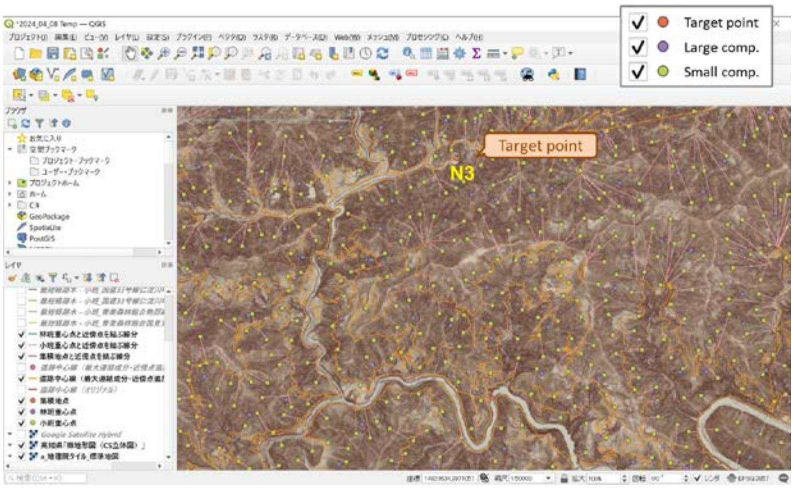



Figure 5. Route search from forest compartments

## 3. Results and Discussion

The density of public roads, including forest roads, was almost the same, regardless of terrain and region, in the forested mountainous area of Japan: 15-18 m/ha. There was no obvious difference in the proportions of road width classification classes among municipalities, also regardless of terrain and region. That is, < 3.0 m: 3.0 - 5.5 m: 5.5 m ≤ = 30-40%: 45-55%: 15%. Although the number of municipalities analysed was limited, a possible explanation would be that it resulted from an overall public road development goal of the Japanese national government.

Figure 6 shows a result of a route search subject to travel distance. The difference between two subject functions, travel distance and travel time, is small. This means that there were almost no alternative routes for each combination of forest compartment and destination. Among the destinations, K1 has larger values for both travel distance and travel time than the other four destinations. This is because K1 is located near the edge of the area. In terms of connection to public roads, almost 40% were of road width less than 3.0 m, where 4-ton class trucks should be used, not 10-ton class ones. Only a fraction of searched routes were connected to roads of width 5.5 m or wider (Figure 7).

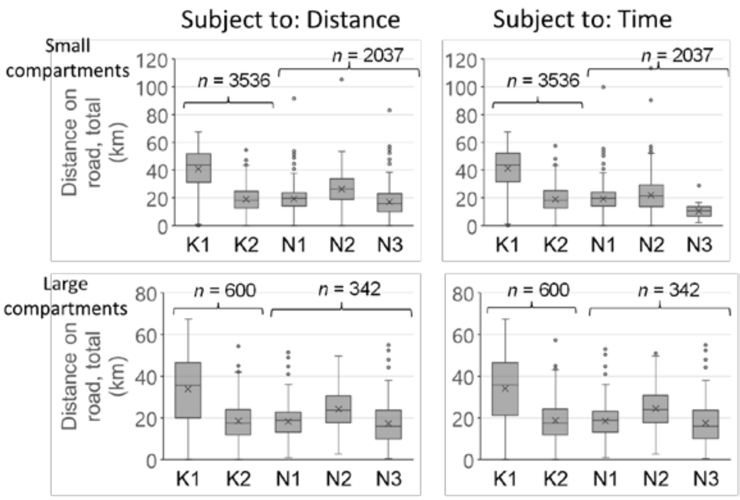



Figure 6. Transportation distance on public roads

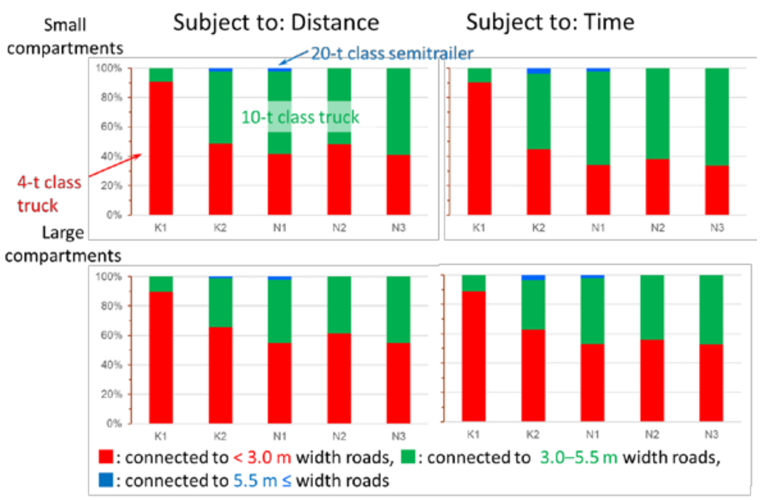



Figure 7. Connection to public roads

Suzuki and Yoshimura (2019) suggested that the threshold for vehicle mode change, i.e., from 4-ton class truck to 10-ton class truck, would be 13-17 km in terms of cost, $CO_2$ emission, and energy consumption criteria. As shown in Figure 8, in most cases, the distance on public roads with road width less than 3.0 m (for 4-t class truck transport) was below the threshold. If this were not the case, it would be necessary to make an intermediate landing and change the vehicle to a 10-ton class truck. However, the result implied that such cases would be a few percent of the total for the analysed conditions.

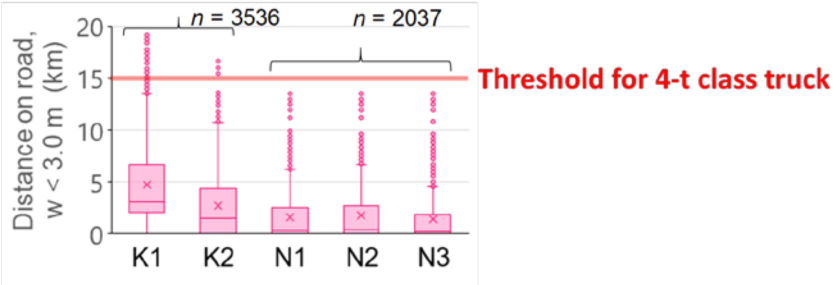



Figure 8. Travel distance on public roads of road width less than 3.0 m

As shown in Figure 7, many forest areas do not allow 10-ton class trucks. In such cases, medium-sized trucks, such as 10-ton class short body trucks (Figure 9), are often used.

August 2023: Shigeto Stock yard in Kami city, Kochi Pref.
October 2022: National forest in Shimanto city, Kochi Pref.

Figure 9. 10-ton class short body trucks

In a curve, the required road width expansion $\varepsilon$ [m] is calculated as follows (Suzuki, 2020):

$$\varepsilon = l^2 / 2R \quad (1)$$

where $l$ is spacing plus front overhang [m] and $R$ is curve radius [m]. Figure 10, where the base figure was in Suzuki et al. (2023), shows the required road widths with curve radius for three types of standard vehicles in corresponding lines, accompanied by the investigated actual road widths. The blue line in Figure 10 represents the road width required for 10 t trucks by adding the required expansion calculated by formula (1). As shown in the figure, the required road width for 10-ton class trucks is just between that for 4-ton class trucks and 10-ton class trucks. There are medium-sized trucks such as 6-t or 8-t in payload in Japan. Such trucks can also be an alternative solution for narrow public roads in mountainous forest areas.

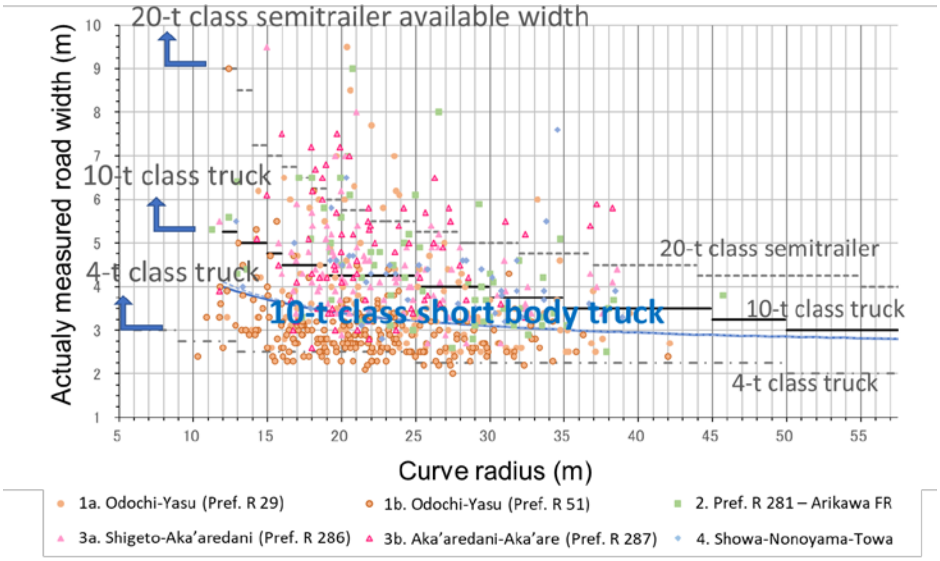



Figure 10. Passing ability of 10-ton class short body truck (modified from Suzuki et al. 2023)

## 4. Conclusion and Suggestions

The road networks in Japan's mountainous areas were analysed for selected municipalities in Kochi Prefecture and some other prefectures in different terrain conditions. The total density of public roads as well as the proportions classified by width were almost the same regardless of the terrain and regions. However, the result was obtained for limited areas, so further research should be conducted including other areas in Japan. The route search analysis from forest compartments to destinations in selected municipalities suggested that medium-sized trucks, i.e. 10-ton class short body trucks or 6-8-ton class trucks, would be part of possible solutions for mountainous forest areas. Intermediate landings would be better than widening narrow public roads in terms of construction costs.

## Acknowledgements

This research was supported by JSPS KAKENHI Grant Nos. 21H03672-23K21785, 22K0574, 22H03800-23K25054, and 24K03148. The authors gratefully acknowledge their assistance.

## References

Kärhä, K., Seuri, M., Donagh, P.M.M., Acuna, M., Kanzian, C., Petković, V., Robert, R.C.G., Costa, L.H.S., da Cruz, R.C., Krumov, T., Bradley, A., Röser, D., Pinto, C., Dian, W., Pandur, Z., Dvořák, J., Jørgensen, M.T., Muiste, P., Irdla, M., Ginet, C., Purfürst, T., Dietz, H.-U., Spinelli, R., Suzuki, Y., Shirasawa, H., Lazdiņš, A., Visser, R., Harvey, C., Skjølaas, D., Moskalik, T., Trzciński, G., Borz, S.A., Muşat, E.C., Triplat, M., Oberholzer, F., Talbot, B., Tolosana, E, von Hofsten, H., Akay, A.O., Bakay, B., Conrad IV, J., Olivera, A. 2024. Overview of Global Long-Distance Road Transportation of Industrial Roundwood. Croatian Journal of Forest Engineering 45: 217-216. [DOI: https://doi.org/10.5552/crojfe.2024.2286 ]

Suzuki, Y. 2020. Chapter 11: Forest Road Design*. (Forest Engineering*. Edited by Yoshioka, Y. Maruzen, Tokyo. 256 p.). 165-180. (in Japanese). [ISBN 978-4-621-30500-3]

Suzuki, Y., Setiawan, A.H., Gotou, J. 2015. Timber harvesting systems in Japan's aging plantation forests: Implications for investment in construction of forest road networks. Journal of the Japanese Forest Society 97:191-202. (in Japanese with English summary). [DOI: http://dx.doi.org/10.4005/jjfs.97.191]

Suzuki, Y., Yoshimura, T. 2019. Formulating cost efficient, low environmental load forestry operations: logging residue transportation and infrastructure provision for broad-leaved tree harvesting. Journal of the Japan Institute of Energy 98:246-253. (in Japanese with English summary). [DOI: http://doi.org/10.3775/jie.98.246]

Suzuki, Y., Yoshimura, T., Hasegawa, H., Aruga, K., Saito, M., Moriguchi, K., Shirasawa, H. 2023. Accessibility of logging trucks on public road networks in a mountainous area. Journal of the Japan Forest Engineering Society 38:115-1226. (in Japanese with English Summary). [DOI: http://doi.org/10.18945/jjfes.38.115]

Suzuki, Y., Yoshimura, T., Hasegawa, H., Aruga, K., Saito, M., Shirasawa, H., Yamasaki, S. 2022. Perspective of road network improvement including public roads over forested area in Japan. Journal of the Japan Forest Engineering Society 37:5-16. (in Japanese). [DOI: http://doi.org/10.18945/jjfes.37.5]

*: The titles are tentative translations from the original Japanese by the authors.

# Using Drone Captured Images to Estimate Productivity of a Loading Operation

**Ebru Bilici[1,2*], Halit Büyüksakallı[3], Gizem Görnaz[4], Abdullah Emin Akay[4]**

[1]University of Idaho, Experimental Forest, College of Natural Resources, Moscow, ID, USA
[2]Giresun University, Dereli Vocational School, 28902 Giresun, Türkiye
[3]Muğla Sıtkı Koçman University, Köyceğiz Vocational School, 48000 Muğla, Türkiye
[4]Bursa Technical University, Faculty of Forestry, 16310 Bursa, Türkiye
[*]ebilici@uidaho.edu

**Abstract**

The loading operation has an important function in the smooth execution of forest operation as it is a transition activity between timber extraction and long-distance timber hauling. Thus, it is crucial to estimate productivity of loading operation and determine the main factors effecting the productivity. The time study analysis is commonly used in productivity estimation of forest operations. Traditional time study analysis, usually done by utilizing time watch, requires two or more personnel who closely observe the logging operation and measure the logs at the landing. However, this field work can be dangerous since several equipment work and move around the operation site. In this study, the productivity of a loader was estimated based on video images which were taken with an "DJI Mavic Pro" model Unmanned Aerial Vehicle (UAV). The study was conducted in a Brutian pine stand located in Muğla Forest Enterprise Chief in the city of Muğla in Türkiye. It was found that the productivity of the loading operation was 25.52 $m^3$/hour. The results indicated that there was a positive significant relationship between productivity and product diameter and volume.

***Key words:*** *Loading operation, time study, productivity, UAV images*

## 1. Introduction

The loading phase of forestry production activities is important after the primary forest products are transported to the landing and then transported to the final forest depot without wasting any time. At this stage, good planning and harmony with other production stages directly affect the efficiency to be achieved. Loading activity is divided into three classes: machine power, manual and cross loading (Aykut. 1984).

Loading activities with machine power are considered in two groups; the loading made with a crane mounted on the transport vehicle and a loading vehicle other than the transport vehicle. The loader integrated into the transport vehicle meets its engine power needs from the transport vehicle. Loaders using this system are divided into three groups; double drum cranes, cable or hydraulic cranes and hiab type cranes (Acar, 2004).

Mobile loading vehicles, which are separate from the transport vehicle, are classified into four groups. These are elevator, tractor-mounted rotary crane, mobile rotary crane and hydraulic gripper mobile loader (Erdaş, 2008). Mobile loader with hydraulic gripper is the most frequently used loading vehicle in many countries. These vehicles are loaders that work on the hydraulic system principle, with a log gripping system on them and the gripping clamps are located at the front or rear of the loader. This loader has the ability to maneuver on hard ground with tires and tracks. The mechanism that allows grapping forest products generally consists of three parts including top quote and two bottom quotes. In Türkiye, forest products, which are removed from the harvesting unit and transported to the final landing, are loaded onto long-distance transportation vehicles using the gripper system integrated into agricultural tractors (Öztürk and Akay, 2007). The agricultural tractors on which the grippers are mounted are not only used in loading operations but also in unloading and stacking operations.

The productivity of mechanical tools used in harvesting operations is mostly determined by their effect on production time. The time study method is the most effective and widely used work measurement technique in calculating production time (Gülci, 2014). Within the scope of time study, the work to be measured is divided into sub-stages and the standard completion time is calculated. For this reason, it is necessary for the implementation of time study to be able to divide the work to be evaluated into sub-stages.

In productivity studies on modern mechanical production machines, time measurements were usually made by using time recording devices (chronometers) and observing the work stages in the area where the machine was operating. Since the production of forest products often takes place in steep and difficult terrain conditions, difficulties may be encountered in applying time analysis in the field. Obtaining high-resolution digital video images of the activities of production machines with an Unmanned Aerial Vehicle (UAV) and making time analysis measurements and productivity calculations based on these images will make significant contributions. In this study, it was aimed to evaluate mechanical production tools with high precision in terms of productivity by using digital images obtained by UAV.

## 2. Material and Methods

### 2.1. Study Area

The study area is in the Brutian Pine (*Pinus brutia*) harvesting unit located in Muğla Forest Enterprise Chief (FEC) of 14,729.10 hectares. Muğla FEC is in the border of Muğla Enterprise Directorate in Regional Directorate of Forestry (Figure 1).

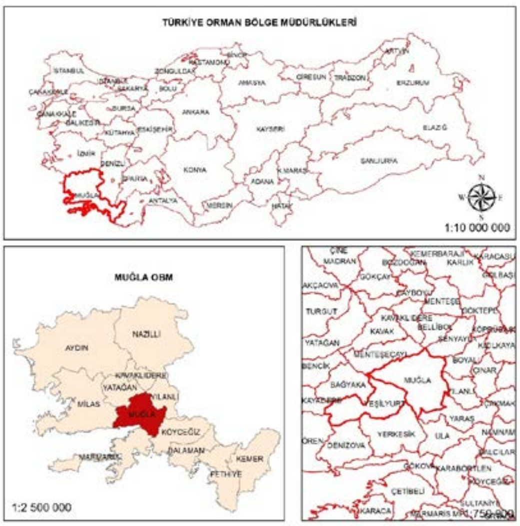



Figure 1. Study area

In the study, Kobelco KW-904 model loader was evaluated during loading operation (Figure 2). The technical specifications of the loader are given in Table 1. Individual work stages were measured for the loading operation. The first work stage begins after the loader loads the product onto the logging truck in the previous cycle and ends when the loader reaches the next product to be loaded. The second stage involves the loader extending the boom, grasping the product, and lifting it. The third stage refers to the time it takes for the loader to reach the logging truck to load. The last stage includes the time it takes for the loader to unload the product into the logging truck and straighten the stack.

Figure 2. UAV image of Kobelco KW-904 loader

Table 1. Kobelco KW-904 technical specifications

| Model | Kobelco KW-904 |
|---|---|
| Engine Power | 90 ps |
| Engine Speed | 2200 rpm |
| Fuel tank capacity | 300 lt |
| Weight | 16550-18350 kg |
| Vehicle Width | 2480 mm |
| Pallet Width | 990 mm |
| Lifting height | 9020 mm |

**2.2. Efficiency Analysis**

In the study, "DJI Mavic Pro" model UAV was used to record time measurements. DJI Mavic Pro, which has the features of providing high-resolution images (12 MP for photos, 4K for videos) and preventing the vibration effect caused by windy weather with its three-axis "gimbal" apparatus, is also one of the widely used unmanned aerial vehicles with its easy portability and durable structure. Flights were carried out at an altitude of 40-60 m to obtain the best quality images and ensure flight safety. The maximum flight time of the UAV was 20 minutes and the images were recorded on a 128 GB memory card. Later, the images taken were analyzed with high precision in the work stages in the office environment.

In the study, video recordings were taken with UAV of 45 tours carried out with the Kobelco KW-904 model loader used in Muğla FEC during the loading. Independent variables taken into account in loading studies with the loader; is the average product diameter (medium diameter), and product volume. In the study, the work stages that occur during productive working time are expressed with the nicknames Y1-4 and are explained below:

Çalışmada yükleme sırasında Muğla OİŞ'de kullanılan Kobelco KW-904 model yükleyici ile gerçekleşen 45 turun İHA ile video kayıtları alınmıştır. Yükleyici ile gerçekleşen yükleme çalışmalarında dikkate alınan bağımsız değişkenler; ortalama ürün çapı (orta çap), ve ürün hacmidir. Çalışmada verimli çalışma zamanı içinde gerçekleşen iş aşamaları L1-L4 rumuzları ile ifade edilmiş ve bunlar aşağıda açıklanmıştır:

L1: The loader reaches the product
L2: Extending the boom and grasping the product
L3: Arriving at the logging truck
L4: Loading and stacking the product

### 2.3. Statistical Analysis

In the statistical analysis, firstly, the descriptive statistical values (average, minimum, maximum, standard deviation) of the time values, independent variables, total time and hourly efficiency of the work stages that make up each work cycle were calculated. The independent variables in the study are average diameter, volume and number of pieces. Then, correlation test was applied to reveal the relationship between independent variables and dependent variables. In the final stage, regression analysis was applied to determine mathematical models for the independent variables that were determined to have a statistically significant relationship with hourly productivity. All these analyzes were carried out using SPSS 20.0 program.

## 3. Results and Discussion

### 3.1. Time Analysis and Productivity

Descriptive statistical findings (minimum, maximum, average and standard deviation) of the independent variables (product diameter, volume and number of pieces) affecting the total time and productivity during production work with the loader are given in Table 2.

Table 2. Statistical findings regarding the independent variables in Muğla FEC

| Variables | Unit | Minimum | Maximum | Average | STD |
|---|---|---|---|---|---|
| Diameter | cm | 22 | 38 | 28.47 | 0.731 |
| Volume | $m^3$ | 0.095 | 0.283 | 0.164 | 0.008 |

Descriptive statistical values (minimum, maximum, average and standard deviation) of time measurements and productivity of the work stages with the loader are given in Table 3. According to the results, when the work stages in a total of 45 cycles recorded during time measurements were evaluated among themselves, it was found that the most time-consuming stage in a cycle was the time taken to extend the boom and grasp the product (0.123 minutes), followed by the time to load the product and stack it (0.121 minutes). In the work of timber production with the loader, the average productivity according to the productive working hours was found to be 25.521 $m^3$/hour.

Table 3. Statistical findings regarding time measurements and total efficiency of loader work stages in Muğla FEC

| Variables | Unit | Minimum | Maximum | Average | STD |
|---|---|---|---|---|---|
| L1 | min | 0.024 | 0.222 | 0.052 | 0.035 |
| L2 | min | 0.031 | 0.398 | 0.123 | 0.087 |
| L3 | min | 0.031 | 0.227 | 0.069 | 0.034 |
| L4 | min | 0.032 | 0.392 | 0.121 | 0.090 |
| Productivity | $m^3$/hr | 9.420 | 66.350 | 25.521 | 12.591 |

### 3.2. Regression Model

Pearson Correlation Test was applied to investigate the relationships between hourly productivity and independent variables for the loader considered in the study. The correlation test results of the loader and production study are given in Table 4. According to the correlation test results, it was determined that there was a positive significant ($p<0.01$) relationship between product diameter, volume and productivity at a 99% confidence level.

Table 4. Correlation analysis findings of the loader for efficiency in Muğla OİŞ

| | | Productivity | Product Diameter | Volume |
|---|---|---|---|---|
| Productivity | Correlation | 1 | 0.641** | 0.633** |
| | P value | | 0.000 | 0.000 |
| Product Diameter | Correlation | 0.641** | 1 | 0.995** |
| | P value | 0.000 | | 0.000 |
| Volume | Correlation | 0.633** | 0.995** | 1 |
| | P value | 0.000 | 0.000 | |

Taking into account the correlation test results, Linear Regression Analysis was used to reveal the relationship between independent variables and productivity. According to the results of One-Way Analysis of Variance, the regression model regarding the loader working time and the independent variable was found to be significant ($p<0.01$) at the 99% confidence level (Table 5). The obtained $R^2$ value (0.414) showed that the regression model explained the loader working time at a moderate level.

Table 5. One-Way Variance Analysis results of the loader for the working time at Muğla FEC

| | Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 2884,472 | 2 | 1442,236 | 14,808 | 0,000[b] |
| | Residual | 4090,528 | 42 | 97,394 | | |
| | Total | 6975,000 | 44 | | | |

a. Independent Variable: Product diameter, Volume

b. Dependent Variable: Productivity

The regression model, which includes the dependent variable (y) representing the productivity and the independent variables (x1 = Product diameter; x2 = volume), is shown in the equation below:

$$y = -38{,}244+(2{,}832)x1 - (102{,}698)x2 \quad (1)$$

## 4. Conclusion

Hourly unit costs of mechanical harvesting tools are high due to purchasing costs and high fuel prices. In order to benefit from the opportunities offered by mechanical production tools, mechanical production methods must be planned taking into account productivity. The most commonly used work measurement technique in calculating the hourly efficiency of mechanical tools is the time study method. Within the scope of time study, the measured work is divided into subsections and standard time is determined with the help of chronometers. In this study, the possibilities of using UAV-based digital images in evaluating the loader's work efficiency were investigated. Additionally, the factors affecting the loader's productive working time and efficiency values were examined. If the outputs obtained in this study and the methodology presented are used by practitioners, the productivity data obtained with high accuracy will make a significant contribution to the calculation of hourly unit costs of production machines. The method can also be used to calculate the hourly productivity of other machines used in forestry, after making the necessary adjustments. For this reason, in future studies, hourly productivity calculations of modern mechanical vehicles that are used or have the potential to be used should be made. Thus, the productivity values of mechanical production tools will be calculated quickly and accurately, contributing to the selection of the most appropriate machine.

## References

Acar, H.H. 2004. Ormancılıkta Transport Ders Notları, Karadeniz Teknik Üniversitesi, Trabzon.

Aykut, T. 1984. Orman Ürünleri Taşımacılığında Araç ve Teknikler, İ.Ü.O.F. Yayın No: 3246/370, İstanbul, S:975.

Erdaş, O. 2008. Transport Tekniği Kitabı. KSÜ Rektörlüğü, Kahramanmaraş, 130/20, 554.

Gülci, N. 2014. Üretim planlamasında hassas ormancılık üzerine araştırmalar. (Doktora Tezi). Kahramanmaraş Sütçü İmam Üniversitesi, Fen Bilimleri Enstitüsü, Kahramanmaraş.

Öztürk, T., Akay, A.E. 2007. Tarım traktörlerinin orman ürünlerinin üretiminde kullanılmak üzere modifiye edilmesi, Orman Kaynaklarının İşlevleri Kapsamında Darboğazlar, Çözüm Önerileri ve Öncelikler, İstanbul: Ekim 17-19.

# Using GIS Techniques to Develop Safe Transportation of Forest Products

**Abdifitah Mohamed Abdullahi[1*], Abdullah Emin Akay[2]**

[1]City University of Mogadishu, K4-Square, Hodon District Mogadishu, Somalia
[2]Bursa Technical University, Faculty of Forestry, 16310 Bursa, Türkiye
[*]amabdullahi@cu.edu.so

## Abstract

Transportation of forest products done by logging trucks is considered as one of the costly and dangerous stages of producing forest products, especially in mountainous regions. In recent decades, large size logging trucks have been preferred during hauling of forest products to minimize the transportation costs. The forest roads with inadequate standards (i.e. road surface, road structures, platform width, curve radius, curve width, etc.) limit the movement and maneuverability of large logging trucks which negatively effects the safety of truck drivers. In this study, it was aimed to use GIS-based network analysis method to develop transportation plan with safety constraint. The study area is located in in the city of Bursa in Türkiye, covering Paşalar, Sarnıç, and Turfal Forest Enterprise Chiefs (FECs). It was found that the total transportation cost increased by 58.23% in the case where safety of the truck drivers was considered. It was found that GIS-based network analysis method can be effectively used to plan transportation of forest products considering safety of logging truck drivers.

***Key words:*** *Forest transportation, logging trucks, operator safety, transportation cost, network analysis*

## 1. Introduction

Forest transportation predominantly relies on the use of logging trucks, a task that is considered hazardous within the forestry sector. This is especially true in Türkiye, where most forested areas are located in rugged and challenging terrain. The safety risks associated with operating logging trucks are largely dependent on the quality of the road infrastructure. In Türkiye, a significant portion (66%) of forest roads are classified as Type-B secondary forest roads, which often require substantial repairs annually due to their substandard construction (GDF, 2012). These inadequate road conditions naturally restrict the operational flexibility of forestry trucks, especially those with large cargo capacities (Buğday and Menemencioğlu, 2014). As a result, effective forest transportation planning must consider not only transportation costs but also the safety concerns associated with driving logging trucks on these challenging roads. This dual focus on cost and safety is essential for ensuring efficient and secure timber transportation within the forestry sector.

Forest transportation predominantly relies on the use of logging trucks, a task that is considered hazardous within the forestry sector. This is especially true in Türkiye, where most forested areas are located in rugged and challenging terrain. The safety risks associated with operating logging trucks are largely dependent on the quality of the road infrastructure. In Türkiye, a significant portion (66%) of forest roads are classified as Type-B secondary forest roads, which often require substantial repairs annually due to their substandard construction (GDF, 2012).

These inadequate road conditions naturally restrict the operational flexibility of forestry trucks, especially those with large cargo capacities (Buğday and Menemencioğlu, 2014). As a result, effective forest transportation planning must consider not only transportation costs but also the safety concerns associated with driving logging trucks on these challenging roads. This dual focus on cost and safety is essential for ensuring efficient and secure timber transportation within the forestry sector.

During the optimization phase of forest transportation planning, which primarily aims at cost reduction, several critical factors need to be considered. These include the length of the road, travel time, and the unit cost of transportation. By assigning these variables to the respective road links within the transportation network, planners can systematically evaluate different routing options. This involves a thorough exploration of alternative paths to identify the optimal route that balances cost efficiency and operational effectiveness. This detailed planning ensures that the chosen route minimizes expenses while maximizing productivity (Chung and Sessions, 2002).

In this study, a GIS-based network analysis method was used to develop optimal transportation strategies, addressing both scenarios of minimizing transportation costs and minimizing driving risks. In the first scenario, the focus was on creating transportation plans that aim to reduce costs. This involves analyzing various routes and their associated expenses to find the most economical options. In the second scenario, the study concentrated on determining transportation plans that prioritize the safest driving conditions for trucks.

## 2. MATERIAL AND METHODS

### 2.1. Study Area

The study area encompasses three Forest Enterprise Chiefs (Paşalar, Sarnıç, and Turfal), situated on the border of MustafaKemalpaşa Forest Enterprise Directorate (FED) at Bursa Forest Regional Directorate (Figure 1). Five forest depots (Sarnıç, Sünlük, Karapınar, Karaorman, Paşalar Depots) and 30 sample landing areas within the Forest Enterprise Chiefs were considered in the study area. The MustafaKemalpaşa FED provided the locations of depots and landings, as well as the quantity of forest products delivered from each landing areas. (Table 1). In the study area various forest products are produced including logs, mine poles, industry wood, and paper wood.

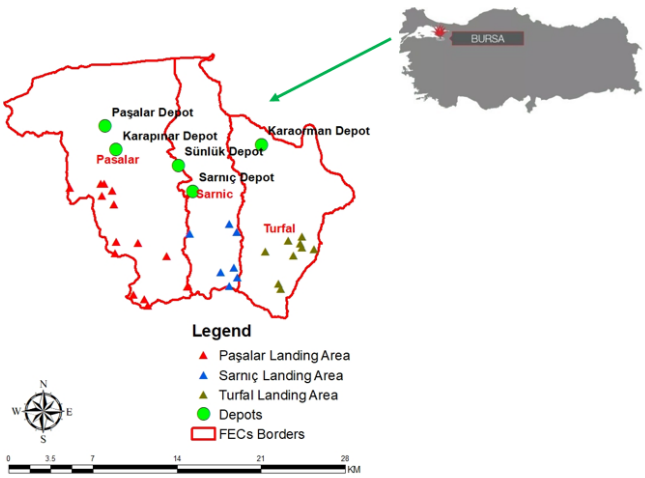



Figure 1. Study area

Table 1. The amount of extracted timber ($m^3$) at the landing areas

| Paşalar | | Sarnıç | | Turfal | |
|---|---|---|---|---|---|
| P1 | 217.49 | S1 | 938.99 | T1 | 165.574 |
| P2 | 878.05 | S2 | 1,300.18 | T2 | 554.387 |
| P3 | 382.62 | S3 | 2,111.65 | T3 | 652.713 |
| P4 | 239.90 | S4 | 1,366.46 | T4 | 702.788 |
| P5 | 2394.53 | S5 | 3,721.15 | T5 | 769.16 |
| P6 | 1206.51 | S6 | 343.99 | T6 | 764.701 |
| P7 | 231.49 | S7 | 544.687 | T7 | 2,100.70 |
| P8 | 412.23 | | | T8 | 206.362 |
| P9 | 499.18 | | | T9 | 436.346 |
| P10 | 414.97 | | | | |
| P11 | 265.80 | | | | |
| P12 | 601.14 | | | | |
| P13 | 752.53 | | | | |
| P14 | 356.05 | | | | |

## 2.2. Network Analysis

The road network layer was generated utilizing data derived from the topographic map acquired from the FED (Forest Enterprise Directorate) (Figure 2). The road network layer's attribute table was assigned five key parameters to each road section: road length, road type, road condition, average vehicle speed, travel time, and road safety score. Road types (asphalt, gravel, forest roads) and conditions (good to poor) were assessed using FED data. The average vehicle speed was determined based on the indicated road types and conditions, as shown in Table 2. Then, logging truck's time was calculated based on speed and road length. Once the travel time was computed, the transportation expenses (€/$m^3$) was determined based on the machine rate (€/h), truck load capacity ($m^3$), and trip time (h). The truck's load capacity and machine rate were 25 tons and 18.57 euros per hour (€/h), respectively.

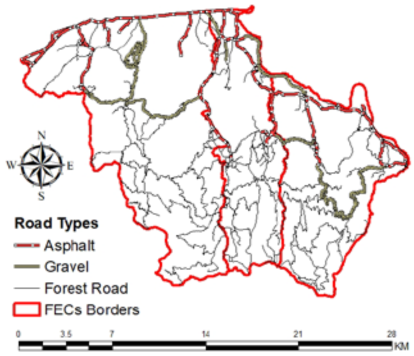



Figure 2. Road network

Table 2. Average logging truck speeds (km/h) for road types and conditions

| Road Type | Road Conditions | | |
|---|---|---|---|
| | Good | Medium | Poor |
| Asphalt road | 60 | 50 | 40 |
| Gravel road | 40 | 30 | 20 |
| Forest road | 25 | 20 | 15 |

In the ultimate phase, the road safety rating will be determined through an expert decision methodology, considering road types and conditions. Road sections' safety rankings will be evaluated on a numeric scale from 1 to 9, with higher scores assigned to sections posing greater risks (Table 3).

Table 3. The road safety scores for road types and conditions

| Road Type | Road Conditions | | |
|---|---|---|---|
| | Good | Medium | Poor |
| Asphalt road | 1 | 2 | 3 |
| Gravel road | 4 | 5 | 6 |
| Forest road | 7 | 8 | 9 |

The "Network Analyst" extension in ArcGIS provides an extensive suite of tools for network-based spatial analysis. In this study, the "new closest facility" approach was utilized to identify the optimal routing options for two distinct scenarios. In the first scenario, transportation planning focused on minimizing transportation expenses. These expenses were assigned to the connections that represent the road segments within the network database. In the second scenario, the emphasis was on ensuring the safest driving conditions for logging trucks. The links representing the road segments in the network database were assigned safety scores. Finally, both scenarios were evaluated based on total transportation costs and the hauling routes for forest products from each landing site.

## 3. Results and Discussion

### 3.1. Transportation Plan for Minimum Cost

The results indicated that the total transportation costs of all tree FECs was 22109.53 € in the first scenario considering only cost. It was found that the total transportation costs for Paşalar, Sarnıç, and Turfal FECs were 7,207.72 €, 8,916.93 €, and 5,984.87 €, respectively.

It was found that the Sünlük Depot did not receive any forest products. All of the forest products from landings in Sarnıç FEC and Turfal FEC were transported to their own depots, Sarnıç and Karaorman Depot, respectively. In Paşalar FEC, forest products from four landings (P1-P4) were transported to Paşalar Depot and five landings (P5-P9) were to Karapınar Depot; however, five landings (P10-P14) were transported to other FEC's Depot (Sarnıç Depot). Figures 3 illustrates the most efficient routes for minimizing transportation costs in the first scenario.

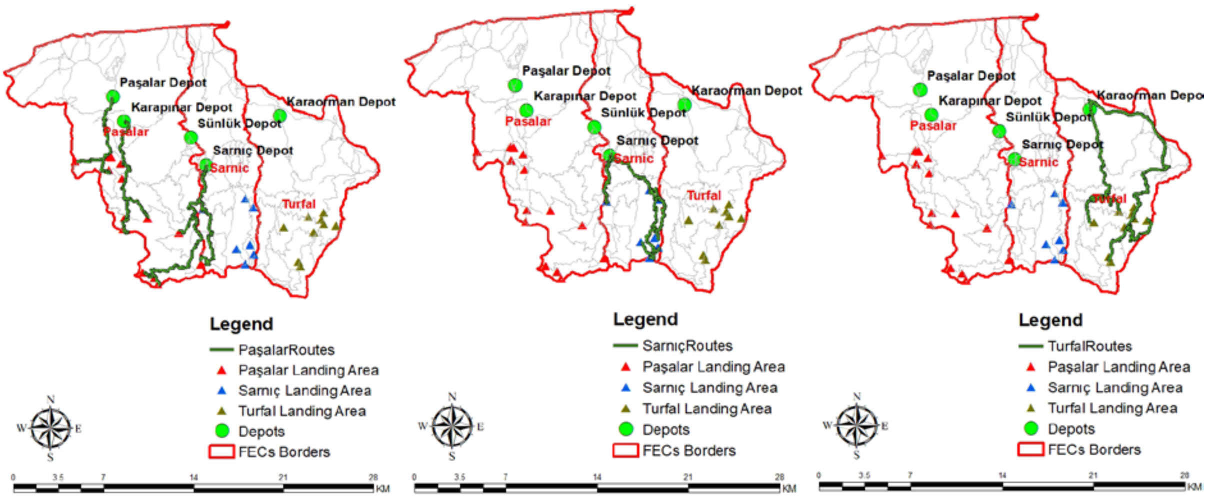



Figure 3. The optimum routes for minimum cost in Paşalar, Sarnıç and Turfal FECs

**3.2. Transportation Plan for Driver Safety**

The results indicated that the total transportation safety costs of all tree FECs was 34,984.22 € in the second scenario considering only safety. It was found that the total transportation safety costs for Paşalar, Sarnıç, and Turfal FECs were 9,812.80 €, 17,238.90 €, and 7,932.53 €, respectively.

The optimum routes that consider safety in the second scenario are shown in Figure 4. It was found that the Paşalar and Sünlük Depots did not receive any forest products. All of the forest products from landings in Turfal FEC were transported to its own depot (Karaorman Depot) (Table 4.8). In Paşalar FEC, forest products from nine landings (P1-P9) were transported to Karapınar Depot and five landings (P10-P14) were to Sarnıç Depot. On the other hand, in Sarnıç FEC, products from one landing (S1) were transported to its own depot (Sarnıç Depota) while from six landings (S2-S7) were to other FEC's Depot (Karaorman Depot).

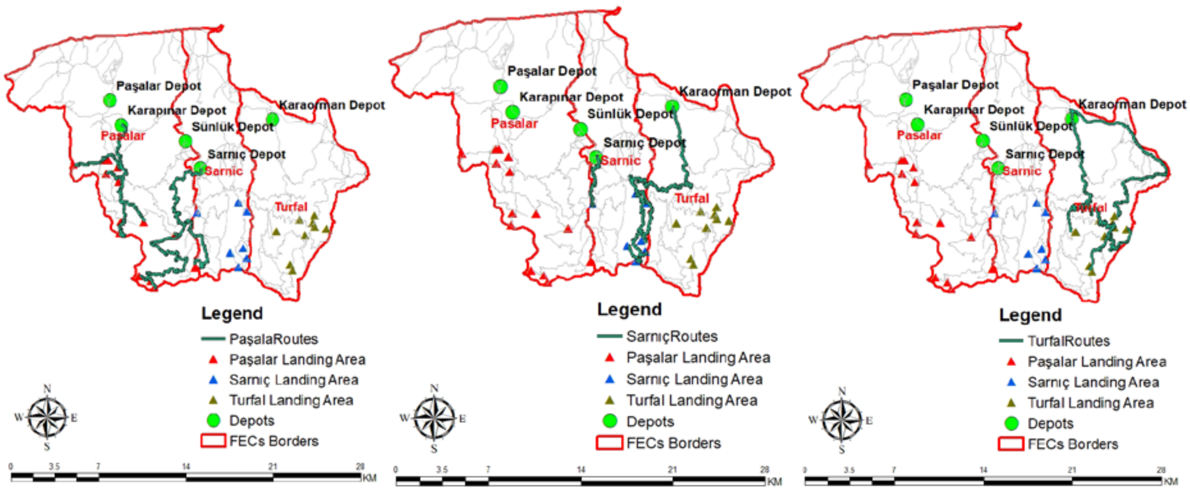



Figure 4. The optimum routes for safety in Paşalar, Sarnıç and Turfal FECs

**4. Conclusion**

In this study, the transportation plans were developed by considering two scenarios in which one aimed to minimize transportation cost and other aimed to provide logging truck drivers with safe transportation. The results indicated that total transportation cost increased in the second scenario of considering safety by 58.23% (12874.70 €). In terms of cost differences in each FEC, transportation cost increased in the second scenario by 36.14%, 93.33%, and 32.54% for Paşalar, Sarnıç, and Turfal FECs, respectively. It was found that the highest amount of increase in the second scenario was in Sarnıç FEC since the total volume transported from Sarnıç FEC was much more than the ones transported from the other FECs. The sample transportation plans indicated that GIS-based network analysis can be effectively used by decision-makers who are willing to pay more to ensure safety of the logging truck drivers. On the other hand, forest transportation activities can be affected when there is any accident or operation delay on the unsafe forest roads, which will increase the total transportation cost and overall cost of producing forest products. Therefore, preferring safe transportation would save money in long run as forest transportation operation will more likely to continue whole season without any delay due to road safety issues. In the future studies, the effects of improving forest roads (Type-B secondary roads) standards on transportation safety should considered. Another subject related with the effect of preferring safety in forest transportation would be investigating the total net revenue of the transportation cost by considering sale prices of the forest products in forest depots. The selling price of the forest products may vary as their prices would be less in forest deport located in rural areas or far from the production sites.

**References**

Buğday, E., Menemencioğlu, K. 2014. Türkiye'de Mevcut Orman Yolu Standartlarının Dikili Ağaç Satışına Uygunluğunun İrdelenmesi. II. Akdeniz Orman ve Çevre Sempozyumu. 22-24 Ekim. Isparta.

Chung, W., Sessions, J. (2002). Optimization of cable logging layout using a heuristic algorithm for network programming,In Proceedings of the Council of Forest Engineering, 16–20 June, Auburn, AL, USA. 104p.

GDF (2012). Strategic Plan (2013–2017), General Directorate of Forestry, Strategy Development Department: Ankara, Turkey, 98p.

# Tree Diameter Measurement Using a Smartphone with Laser Technology

**İnanç Taş[1], Hajri Haska[2*], Abdullah Emin Akay[1], Halil İbrahim İnce[1], Olsi Miraci[2]**

[1]Bursa Technical University, Faculty of Forestry, 16310 Bursa, Türkiye
[2]Metropolitan University of Tirana, Coordinator for Innovation, science and Projects, Tirana, Albania
*hajrihaska@gmail.com

**Abstract**

LiDAR remote sensing technology offers users the ability to make direct measurements and predictions in various areas of forestry. The capacity of this technology to determine and monitor stand characteristics is quite effective. The breast height diameter (DBH) of trees can be determined with high accuracy by processing terrestrial LiDAR data. LiDAR-based point clouds can be divided into a horizontal grid to detect stems. Point clusters 1.3 meters above the ground are used for DBH calculation. DBH can be determined using shape recognition techniques on these clusters. In recent years, 3D models of objects can be developed using smartphones with LiDAR sensors, and the diameters of trees can be also determined in a short time and with high accuracy using smartphone applications. In this study, the diameter of 36 Black pine trees (*Pinus nigra*) was measured using an iPhone 14 Pro smartphone and the ForestScanner application. In practice, diameter measurements of sample trees were made with calipers and the results were compared using statistical methods. According to the results of the correlation analysis, it was determined that there was a strong positive relationship between LiDAR and caliper measurements with a 99% confidence interval ($p < 0.01$). This result shows that both measurement methods are highly compatible with each other and that LiDAR technology gives consistent results with the data obtained with the caliper.

***Key words:*** *LiDAR, DBH, stand properties, smart-phone applications*

## 1. Introduction

### 1.1 LiDAR Technologies

In recent years, Light Detection and Ranging (LiDAR) data has become extremely useful as it provides information such as object height and characteristics, as well as statistics over large regions. LiDAR can obtain this information by capturing the intensity of backscattered pulses and 3D coordinates. A LiDAR device can generate a 2D angle image and a 3D image containing angle/distance information. Because it controls when light is emitted, it can directly measure distance based on the round-trip time (ToF) to the object at a given pixel. If there is sufficient signal, the 3D image can also be in grayscale and color. Coherent LiDAR can detect speed very precisely (Gharineiat et al., 2022).

LiDAR remote sensing technology offers the ability to make direct measurements and predictions in a variety of important areas in forestry. The role of this technology in determining and monitoring forest characteristics is quite broad. Using large footprint systems, LiDAR can directly measure canopy height, lower canopy topography, and the vertical distribution of surfaces cut between the canopy top and the ground. Other forest structural properties, such as aboveground biomass, can be modeled from these direct measurements.

### 1.2. Direct Measurements and Predictions

The canopy height is calculated using the initial and final return signals from the LiDAR. Large footprint systems represent the top of the canopy using the first return signal above a noise threshold and the ground using the midpoint of the last return signal. This method can accurately measure canopy heights in a variety of vegetation such as deciduous, pine, Douglas fir, and dense tropical wet forests (Dubayah, et al., 2000). Aboveground biomass is modeled directly from measured canopy height and lower canopy topography. Strong connections between vegetation height and other biophysical properties play a critical role in these modellings.

LiDAR technology is also very effective in calculating tree breast height diameter (DBH). The DBH of trees can be determined with high accuracy by accurate processing of LiDAR data (Vatandaşlar et al., 2022). A digital terrain model (DTM) can be produced from LiDAR data and it forms the basis for DBH measurements. LiDAR point clouds are divided into a horizontal grid to detect the body. For DBH calculation, sets of points approximately 1.25-1.35 meters above the ground can be used. Body diameters are determined by using shape recognition techniques on these clusters (e.g. Hough transform or least squares circle fitting). The relationship between tree trunk height and diameter allows for a more accurate estimate of breast diameter. More comprehensive models can be generated by associating these relationships with factors such as species composition, climate and field quality.

## 2. Material and Methods

### 2.1. Study Area

This study was carried out in the black pine (*Pinus nigra*) field located around Bursa Technical University Mimar Sinan Campus. The average planting distance of trees in the study area was 4 meters and the average DBH of the trees was 35 cm (Figure 1).

Figure 1. Study area

### 2.2 Forest Scanner Application

ForestScanner is an application available for free on the App Store (https://www.apple.com/app-store). The app works on iPhones and iPads with a time-of-flight (ToF) LiDAR sensor, and the maximum scanning distance of the sensor is 5 meters. When the device is moved, ForestScanner scans surrounding object surfaces to obtain a 3D point cloud. This point cloud and 3D triangular meshes appear on the screen in real time during scanning, allowing users to visually recognize scanned surfaces. The point cloud is colored with RGB information collected by the on-device camera (Tatsumi et al., 2023). This device with LiDAR technology was used to measure the breast diameter of trees in the study area (Figure 2).


Figure 2. Interface of the application used

**2.3 Data Collection and Analysis**

During field studies, the breast diameter of each sampled tree was first measured manually with a caliper and noted. Each tree was then scanned using the Forest Scanner app from a distance of 2 meters with an iPhone 14 Pro. Scanning each tree took an average of 30 seconds. Shooting quality and speed were increased by reducing the shooting distance from 5 meters to 2 meters (Figures 3). Breast diameter measurements of the trees were made using caliper and LiDAR technologies, and these data were analyzed using the IBM SPSS Statistics 20 program.

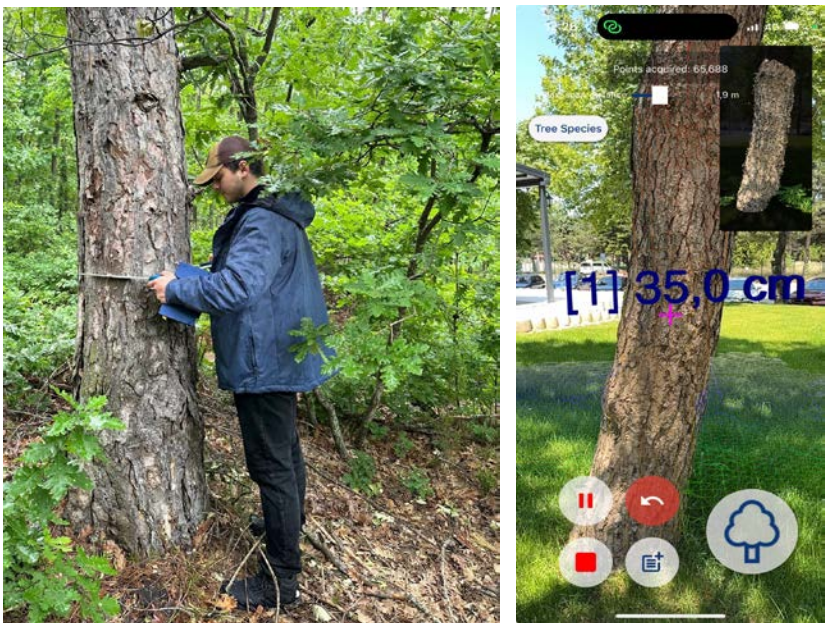



Figure 3. Images taken while measuring with a caliper (left) and measuring with a device (right)

## 3. Results and Discussion

DBH measurements of the trees were made using caliper and LiDAR methods and the descriptive statistics indicated in Table 1 were obtained. Descriptive statistics included minimum, maximum, mean and standard deviation values for both methods.

Table 1. Descriptive statistics for Caliper and LiDAR methods

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic |
| Caliper | 37 | 22.50 | 63.25 | 39.4743 | 8.14147 |
| LiDAR | 37 | 22.10 | 63.60 | 39.0189 | 8.36915 |
| Valid N (listwise) | 37 | | | | |

According to the correlation analysis results, there is a strong positive relationship between caliper and LiDAR measurements. Pearson correlation coefficient was found to be 0.996, and the significance level is 0.000 ($p < 0.01$). These values show the strength and direction of the relationship between the two measurement methods (Table 2).

Table 2. Correlation values between Caliper and LiDAR methods

| | | Caliper | LiDAR |
|---|---|---|---|
| Caliper | Pearson Correlation | 1 | .996** |
| | Sig. (2-tailed) | | .000 |
| | N | 37 | 37 |
| LiDAR | Pearson Correlation | .996** | 1 |
| | Sig. (2-tailed) | .000 | |
| | N | 37 | 37 |

**. Correlation is significant at the 0.01 level (2-tailed).

According to the paired sample t-test results, there is a statistically significant difference between caliper and LiDAR measurements. The average difference was 45541, and it was determined that this difference was significant ($p < 0.001$) at the 95% confidence interval. The significance level is 0.001, and since it is less than 0.05, it can be said with 95% confidence that there is a significant difference between the two measurement methods. These results show that the difference between the two measurement methods is statistically significant (Table 3). These results show that LiDAR technology gives results compatible with the caliper. In this way, it can be said that LiDAR can be used as a reliable measurement tool in the field of forest engineering.

Table 3. Paired Sample t-Test Results for Caliper and LiDAR Methods

| Paired Samples Test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | Caliper - LiDAR | .45541 | .79073 | .12999 | .19176 | .71905 | 3.503 | 36 | .001 |

**4. Conclusion**

This study was carried out to evaluate the usability and accuracy of smartphones with laser technology in tree diameter measurement in a black pine (Pinus nigra) stand. In the study, measurements made with the traditional measurement method, caliper, were compared with smartphones with LiDAR technology and the ForestScanner application.

The findings obtained as a result of the study can be summarized as follows:

• Measurements made with LiDAR technology showed a high degree of correlation with measurements made with the traditional caliper method. This shows that LiDAR technology provides high accuracy and reliability in DBH measurement.

• Especially in measurements made on black pine trees with an average diameter of 35 cm, the deviation rate of LiDAR technology remained minimal.

• Measurements made using LiDAR technology were completed much faster compared to traditional methods. By reducing the shooting distance from 5 meters to 2 meters, measurement quality and speed have increased further.

• The use of LiDAR technology has significantly increased the efficiency of field measurement operations and saved labor.

• LiDAR technology and ForestScanner application available on smartphones have a user-friendly interface and can be easily used in the field. This will contribute to the widespread use of technology integration in forestry activities.

• Considering the equipment and time costs required by traditional methods, LiDAR technology provides a significant advantage.

This study showed that smartphones with laser technology can be used effectively to measure tree DBH. LiDAR technology offers faster, more efficient and accurate results compared to traditional methods. Integration of technological innovations in the forestry sector can provide significant savings in both time and cost by optimizing data collection processes.

**References**

Dubayah, R., Drake, J. 2000. Lidar remote sensing for forestry applications. Journal of Forestry. 98(6): 44-46.

Gharineiat, Z., Fayez Tarsha Kurdi, F.T., Campbell, G. 2022. Review of Automatic Processing of Topography and Surface Feature Identification LiDAR Data Using Machine Learning Techniques. Remote Sens.14(19): 4685.

Tatsumi, S., Yamaguchi, K., Furuya, N. 2023. ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad. Methods in Ecology and Evolution. 14: 1603–1609.

Vatandaşlar, C., Zeybek, M., Çankaya, E.Ç., Demiraslan, T., Şahin, C., Gündüz, Y., Korkmaz, Ü., Avcı, M.L. 2022. El tipi mobil LiDAR teknolojisinin orman envanterlerinde kullanımı: Artvin-Şavşat örneği . Ormancılık Araştırma Dergisi. 9 (1): 81-96.

# Use of Environmentally Friendly Logging Operations in The Concept of Small Scale Forestry

**Hajri Haska [1*], Sinem İnan[2], Abdullah Emin Akay[2]**

[1]Metropolitan University of Tirana, Coordinator for Innovation, science and Projects, Tirana, Albania
[2]Bursa Technical University, Faculty of Forestry, 16310 Bursa, Türkiye
[*]hajrihaska@gmail.com

**Abstract**

One of the most important principles of forestry is sustainability which must be taken into consideration during afforestation, regeneration, protection and timber extraction activities carried out in forests. However, since the wood raw material scattered in the forest is extracted under very difficult conditions, logging activities may cause damage on residual stands. If environmentally friendly logging techniques are implemented, residual trees and saplings, and wood-based end products would be protected, and the sustainability of the forests can be ensured. Small-scale forestry operations used in non-industrial and site-specific forestry offer alternative methods suitable for environmentally friendly timber extraction activities. In small-scale forestry operations, felling is generally carried out with a chainsaw, and small and medium-sized mechanized equipment and systems are preferred for logging operations. Mechanized logging equipment and systems preferred in small-scale forestry operations, which are mostly used to remove medium and small diameter products from the harvesting units, may include skidding with portable winch, ATV logging, and chute system. In this study, these small-scale logging techniques were introduced and their advantages in environmental impact were presented based on the information obtained from the previous studies. As a result, small-scale logging equipment and systems, whose purchase price and operating costs are not very expensive, can be purchased and used at low cost by logging contractors carrying out timber extraction activities. In addition, the systems used in small-scale forestry operations have a much lower impact on the residual trees in the stands.

***Key words:*** *Environmentally friendly logging, stand damage, soil impact, small scale forestry*

## 1. Introduction

The most costly and time-consuming stage of timber production is timber extraction work. Extraction costs increase especially in forested areas where land conditions are not suitable and there is no sufficient road network (Aykut and Öztürk, 1998). One of the most important principles of forestry is sustainability and this principle must be taken into consideration during all kinds of maintenance, regeneration and harvesting activities in forests. However, since the collection of primary forest products scattered in the forest is carried out under very difficult conditions, injuries may occur to the roots and trunk parts of residual trees, saplings and products during extraction (Yılmaz and Akay, 2008). At the same time, timber extraction also causes negative effects on forest soil (Akay et al., 2007). In other words, the sustainability of forests can be negatively affected due to timber extraction activities. Thus, necessary precautions should be taken to minimize the damage that may occur to the residual stand and ecosystem during timber extraction.

If the timber extraction is carried out carefully and meticulously, planted trees, saplings, forest soil and primary forest products will be protected and the sustainability of the forests can be ensured (Aykut and Öztürk, 1998). For this, especially in terms of sustainable forestry, different and variable factors must be examined in a multi-faceted manner and the most appropriate extraction method must be selected and applied among many alternatives (Eroğlu, 2012). Considering all this, forests, which are among the leading natural resources, need to be managed according to precision forestry principles in order to meet the needs of today and future generations. The precision forestry approach aims to provide optimum efficiency from forest resources and minimize environmental damage by using modern techniques and technological tools in order to make economic, environmental and sustainable decisions in forestry studies (Gülci, 2014).

Data needed in precision forestry studies is obtained as a result of high-accuracy measurements using modern and technological methods. Data collection methods are categorized under three separate groups: terrestrial measurements, remote sensing technologies and real-time sensing systems (Ziesak, 2006). Data obtained in precision forestry studies are processed and analyzed using modern techniques and analytical methods (Kovácsová and Antalová, 2010). In this context, the most commonly used methods are Geographic Information Systems (GIS) and computer-aided decision support systems.

When forest product production is considered in the context of precision forestry approach, planning and implementation of site-specific activities should be implemented using modern techniques and technologies in order to increase the quality of the products, reduce losses and increase the economic value, while taking into account stand damages (Taylor et al., 2002). In this context, it becomes clear that forestry activities carried out during the production of forest products (logs, mine poles, industrial wood, etc.) and biomass (fuelwood, cutting residues, etc.) should be carried out with a precision forestry approach.

Small-scale forestry operations used in non-industrial and site-specific forestry in the international literature offer alternative methods suitable for the precision forestry concept (Sennblad, 1993). In small-scale forestry operations, cutting operations are generally carried out with a chainsaw, and small and medium-sized mechanical tools and systems are preferred for logging operations. In this respect, these tools and systems, whose purchase price and operating costs are not very expensive, can be easily procured and used at low cost by cooperatives or teams carrying out compartment removal works. In addition, the systems used in small-scale forestry operations have a much lower impact on the residual trees in the stand and the forest soil (Lyons, 1994). These systems are successfully applied in coniferous and/or broadleaf stands with different characteristics in various regions of the world (Kent et al., 2011).

In this study, the extraction activities carried out during wood raw material and biomass production within the scope of small-scale forestry were examined from an environmental perspective. As an environmental factor, the residual tree damage caused during the production of forest products was considered.

## 2. Material and Methods

### 2.1 Small Scale Forest Operations

Modified agricultural tractors are the most commonly used for timber extraction work in small-scale forestry operations (Akay, 2005; Jourgholami, 2014) (Figure 1). In this context, agricultural tractors are used in different ways, including skidder, loader and forwarder (Öztürk and Akay, 2007). During modification processes, a tractor crane is added to the rear of agricultural tractors, a hydraulic loading arm is mounted to the front or rear, and a special trailer or trailer is connected to transport forest products (Russell and Mortimer, 2005). In addition, 4x4 traction power and equal loading rate for the axles are provided and a protected operator cabin is added (Öztürk and Akay, 2007).

Other mechanical tools and systems preferred in small-scale forestry operations, which are mostly used to remove medium and thin diameter products from the stand, include portable hand winch, ATV and crane-integrated chute system. In areas where forest products are not suitable to be extracted from the stand by human or animal power and in cases where extracting them from the stand by tractor is not preferred, timber extraction from the stand by pulling cables with portable hand winches appears as an important alternative (Gülci, 2014) (Figure 2).

There has been an increasing interest in the use of ATV (All Terrain Vehicle) in recent years within the scope of small-scale forestry operations (Russell and Mortimer, 2005). ATVs, which have not yet found a place in the extraction of forest products from the stand, are generally 4-wheeled (all driven) off-road vehicles, developed for recreational purposes in the early years (Figure 3). Today, ATVs used in forestry work in different parts of the world are modified with some special equipment, such as agricultural tractors. In this way, it can perform the functions of skidding, pulling with a crane, and carrying and loading with the special trailer mounted at the back during removal from the compartment. For a safe and efficient operation with an ATV, care should be taken to ensure that the terrain and slope conditions are suitable, the load to be carried does not exceed the ATV's own weight, and trained operators are employed (Russell and Mortimer, 2005).

In the extraction applications explained above, wood raw material can be skidded on the ground or in combination with a skidding cone. When skidding cones are used, the risk of products getting stuck on remaining trees, logs and other obstacles is reduced, which increases operational efficiency and reduces stand damage (Akay et al., 2014a). The plastic chute system, which is used to a limited extent, also gives good results in timber extraction (Akay et al., 2014c). The plastic chute transportation system provides great convenience, especially in extracting medium and thin diameter products and biomass firewood from the stand. In addition, it offers important benefits such as reducing stand damage and keeping quality and volume losses in the transported product to a minimum (Acar and Eroğlu, 2003). In recent years, chute system studies integrated with a portable winch have been carried out in order to pull wood raw materials up the slope in mountainous areas (Figure 4). In these studies, it was stated that this system, reinforced with a portable winch, is more economical, practical, efficient and environmentally friendly compared to the traditional methods used in timber extraction works (Gülci, 2014; Zarifoğlu, 2014).

Figure 1. Cable pulling with agricultural tractor

Figure 2. Cable pulling with a portable winch

Figure 3. Skidding with ATV and skidding cone

Figure 4. Chute system integrated with winch

**2.2 Choosing the Optimum Method**

The determination of timber extraction alternatives is mainly evaluated depending on the technical characteristics of the land. The most important factor depending on the technical characteristics of the land is the slope of the land where logging will take place, followed by the presence of facilities and vehicles for commissioning. The data required to accurately represent the land slope in a digital environment can be produced with the RTK (Real Time Kinematic) GPS system, which is one of the most used terrestrial data collection methods in precision forestry (Gülci et al., 2015).

Slope classes determined by IUFRO for forest harvesting operations is divided into five groups: Flat land (0 – 10%), Slightly sloped land (11 – 20%), Medium-sloped land (21 – 33%), Steep land (34 – 50%), and Very steep land (> 50%). Road construction costs are not very high on flat and slightly sloped lands, and transport combinations with forest roads and skidding roads offer a suitable alternative. In these areas, extraction from the compartment can be carried out with mechanical tools used in small-scale forestry, such as a portable hand winch (Akay et al., 2014a; 2014b). In addition, agricultural tractors and ATVs can also be used in logging applications by skidding in these fields (Eubanks, 2011).

In medium-sloped lands, forest road construction is difficult and costly due to the slope, and roads that are not properly planned can cause more damage to the forest. Human and animal power cannot be used because they are insufficient to carry it up the slope. In these areas, cable pulling can be done with agricultural tractors and portable winches suitable for small-scale forestry operations, while skidding can be done on the ground with agricultural tractors (Gülci, 2014). Since road construction in steep and very steep terrain is difficult, costly and environmentally damaging, powerful agricultural tractors and forest tractors can move on the tractor track without entering the forest area and pull cables or overhead lines with cranes can be used. At the same time, in these areas, extraction can be done with plastic chute systems, which are one of the methods of small-scale forestry operations (Gülci, 2014). In order for the chute system to be used efficiently, the slope of the land must be suitable, and it must be installed at an angle to the contour lines on high slopes.

### 2.3 Stand (Residual Tree Damage) Damage

Extraction works that are not properly planned and applied to the land can cause significant damage to the stand. The damages that occur in the stand during logging and the degree of these damages depend on the length of the transported products, slope, stand density, creation of skidding strips and tractor roads, and the selection of the skidding method. Residual tree damage, which stands out in most studies on stand damage occurring during the production of forest products, will be evaluated as the main environmental factor in this study. In determining residual tree damage; coordinate data, diameters of injured trees, width and length of the wounds, wound type (sapwood or bark damage) and height from the ground should be collected in the field studies.

## 3. Conclusion and Suggestions

Inadequate use of mechanical production methods increases the cost of extraction work and may cause damage to the forest ecosystem. In the production of forest products, planning and implementation of site-specific production studies using modern techniques and technologies with a precision forestry approach will reduce stand damages, protect the quality of the products, minimize losses and increase the economic value. If the approaches presented in this study are implemented by practitioners, the following benefits and widespread effects are anticipated:

- The site-specific small-scale forestry operations to be evaluated in this study will offer alternative methods to be used in forestry.
- Considering ecological factors within the scope of precision forestry, methods will be developed to reduce the environmental effects of logging on the ecosystem.
- Considering environmental sensitivities, the application of portable hand winch will contribute to the implementation of environmentally friendly forestry operations.
- The application of the ATV method, which is used in timber extraction works in different parts of the world, in the project will serve as an important example for the use of this method in technically suitable areas.
- In the study, the skidding cone will be applied in different logging methods during skidding, which will contribute to the widespread use of it in production studies.

## References

Acar, H.H. ve Eroğlu, H. 2003. Dağlık Arazide Üretilen İnce Çaplı Odunların Fiberglass Yöntemi ile Bölmeden Çıkarılması İmkanları Üzerine Bir Araştırma, KTÜ Araştırma Fonu Projesi, No: 22.113.001-2, Ocak.

Akay, A.E. 2005. Using Farm Tractors In Small-Scale Forest Harvesting Operations, Journal of Applied Sciences Research. 1(2): 196-199.

Akay, A.E., Yuksel, A., Reis, M., Tutus, A. 2007. The Impacts of Ground-based Logging Equipment on Forest Soil. Polish Journal of Environmental Studies. 16(3): 371-376.

Akay, A.E., Sert, M., Gülci, N., Gülci, S. 2014a. Küçük Ölçekli Ormancılık Çalışmalarında Ekolojik Bir Yaklaşım: Benzinli El Vinci. Ekoloji 2014 Sempozymu. 01-04 Mayıs. Gazimağusa-KKTC, Kıbrıs.

Akay, A.E., Sert, M., Gülci, N. 2014b. Hafif Eğimli Arazilerde Benzinli El Vinci ile Bölmeden Çıkarma Çalışmalarının Verim Açısından Değerlendirilmesi. II. Ulusal Akdeniz Orman ve Çevre Sempozyumu. 22-24 Ekim, Isparta.

Akay, A.E., Çankal, H., Gülci, N., Gülci, S. 2014c. Tomruk Üretiminde Kullanılan Oluk Sisteminin Verimlilik ve Çevresel Açıdan Değerlendirilmesi. II. Ulusal Akdeniz Orman ve Çevre Sempozyumu. 22-24 Ekim, Isparta.

Aykut T., Öztürk T. 1998. Vinçli Hava Hatlarında Yapılan Zaman Etüdleri Ve Sonuçları, İ.Ü.Orman Fakültesi Dergisi, 48: 61-73.

Eroğlu, H. 2012. Dağlık Arazide Farklı Bölmeden Çıkarma Tekniklerinin Orman Toprağının Sıkışmasına Etkisi. Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi. 13(2):213-225.

Eubanks, E. 2011. All-Terrain and Utility Terrain Vehicle Safety: Alternative Vehicles for Towing Trail Grading Equipment. United States Department of Agriculture. Forest Service National Technology & Development Program Greulich FR, Hanley DP, McNeel JF, Baumgartner D. 1999. A primer for timber harvesting. EB1316. Washington, DC: WSU Cooperative Extension. 33 p.

Gülci, N. 2014. Üretim Planlamasında Hassas Ormancılık Üzerine Araştırmalar. Doktora Tezi, Kahramanmaraş Sütçü İmam Üniversitesi, Orman Fakültesi, Kahramanmaraş. 264.

Gülci, N., Akay, A.E., Erdaş, O., Gülci, S. 2015. Forest operations planning by using RTK-GPS based digital elevation model. Journal of the Faculty of Forestry Istanbul University. 65(2): 59-68

Jourgholami M. 2014. Productivity and cost of a small-scale timber forwarding system using farm tractors in the Hyrcanian forest, northern Iran. Taiwan J For Sci 29(2):103-16.

Kent, T., Kofman, P.D., Coates, E. 2011. Harvesting wood for energy; Cost-effective woodfuel supply chains in Irish forestry. Dublin.

Kovácsová P., Antalová M. 2010. Precision Forestry - Definition and Technologies. Journal of Forestry Society of Croatia, 134(11-12): 603-611.

Lyons, J. 1994. Low ground pressure small-scale harvesting machines, July 1994.

Öztürk, T., Akay, A.E. 2007. Tarım Traktörlerinin Orman Ürünlerinin Üretiminde Kullanılmak Üzere Modifiye Edilmesi. Orman Kaynaklarının İşlevleri Kapsamında Darboğazlar, Çözüm Önerileri ve Öncelikler. Ekim 2007. Harbiye Askeri Müze ve Kültür Sitesi. İstanbul. pp. 1111-1120.

Russell F, Mortimer D. 2005. A review of small-scale harvesting systems in use worldwide and their potential application in Irish.

Sennblad, G. 1993. Eurofortech Thinning Harvesting and Extraction (Small-scale Technology), November 1993.

Taylor, S., Veal, M., Grift, T., Mcdonald, T., Corley, F. 2002. Precision Forestry: Operational tactics for today and tomorrow. 25th Annual Meeting of the Council of Forest Engineers. 16-20 June. Auburn University, Auburn, Alabama.

Yılmaz, M., Akay, A.E. 2008. Stand Damage of a Selection Cutting System in an Uneven Aged Mixed Forest of Çimendagi in Kahramanmaras-Turkey. International Journal of Natural and Engineering Sciences. 2(1):77-82.

Ziesak, M. 2006. Precision Forestry - An overview on the current status of Precision Forestry. A literature review. In: "Precision Forestry in plantations, semi-natural and natural forests" IUFRO Precision Forestry Conference. 5-10 March. 2006 Technical University Munich. Stellenbosch University, Germany.

# The Biodiversity of Georgian Forests and the Current Situation

**Rezo Vasadze[1*], Guguli Dumbadze[2], Sesili Gatenadze[2]**

[1]N(N)LE Georgian Patriarchate St. Tbel Abuseridze Teaching University, The Service Against Forest Pests and Diseases, Ajara Forestry Agency, Batumi, Georgia
[2] Department of Biology, Batumi Shota Rustaveli State University, Batumi, Georgia
[*]rezovasadze1961@gmail.com

## Abstract

Georgia, situated at the crossroads of Europe and Asia, boasts a rich and diverse ecosystem. It hosts a remarkable array of ecosystems shaped by diverse climatic conditions, ranging from humid-subtropical to dry-continental. Forests, which cover approximately 44.5% of Georgia's land area, harbor over 5,000 species of wild plants, including significant Tertiary relics such as *Rhododendron ponticum, Taxus baccata, Castanea sativa, etc*. Particularly in the Ajara region, which is recognized as one of 34 global biodiversity hotspots by the International Union for Conservation of Nature (IUCN), biodiversity remains a key ecological asset. Despite this richness, the forests of Georgia face increasing threats from invasive pests, diseases, and the impacts of climate change. This study evaluates the current biodiversity, forest health, and management challenges, with a focus on the Ajara region. Using data from the 2023 National Forest Census and field observations, the research examines species distribution, vegetation zonation, and the effects of environmental stressors on forest ecosystems. Moreover, it assesses current pest management and forest restoration efforts, emphasizing sustainable practices to mitigate the risks posed by climate change and invasive species. Results indicate that Georgia's forests contain a rich diversity of angiosperms, gymnosperms, and spore-bearing plants, distributed across various elevational zones. However, climate change-induced pests, such as *Cydalima perspectalis and Cryphonectria parasitica*, are causing significant ecological damage. Integrated Pest Management (IPM) strategies, including the use of pheromone traps and biological controls, have shown some success in combating these threats. Nevertheless, enhanced monitoring and climate-adaptive management are essential for ensuring the sustainability of these forests.

***Key words:*** *Georgia, forest, biodiversity, pest control, climate change*

## 1. Introduction

Georgia, located at the confluence of Europe and Asia, boasts an exceptional diversity of flora due to its varied geography. The country's landscapes, spanning from the Caucasus Mountains to the Black Sea coast, host ecosystems that range from humid-subtropical to semi-arid. This diversity of climates allows Georgia's forests, which cover 44.5% of the total land area, to support over 5,000 species of plants, many of which are Tertiary relics (Gagnidze, 2000; Goginashvili et al., 2021).

Georgian forests are recognized as one of the world's 34 biodiversity hotspots, according to the International Union for Conservation of Nature (IUCN). Georgia's, especially Ajara's unique role as a refuge during the Ice Age preserved numerous species that have since disappeared from the rest of Eurasia, making it a critical area for global biodiversity conservation (Ketskhoveli, 1959).

However, the forested area in Georgia is decreasing daily due to various negative factors such as fire, pollution, disease, insects, and incorrect planning. Georgia's forests are currently under significant threat from invasive species, pathogens, and the increasing impacts of climate change. The introduction of invasive species like the boxwood moth (*Cydalima perspectalis*) and bark beetles (*Ips typographus L., Dendroctonus micans Kugel., Ips sexdentatus Boern.*) (Vasadze et al., 2023; Vasadze R.&Vasadze Z . 2024; Beridze et al., 2024), along with the proliferation of chestnut blight *(Cryphonectria parasitica*) (Dumbadze et al., 2019), have caused substantial damage to key tree species. Moreover, climate change—evidenced by rising temperatures and altered precipitation patterns—has further weakened forest resilience, leaving them more vulnerable to pests and diseases (Gokturk et al, 2022; National Forest Census, 2023).

This paper aims to provide a comprehensive analysis of the biodiversity and forest ecosystems of Georgia, with a focus on the Ajara region. By examining the distribution of key plant species, the vertical zonation of vegetation, and the impact of environmental stressors on forest health, this study seeks to highlight the ecological significance of Ajara's forests and to identify the major challenges they face. The ultimate goal is to contribute to ongoing conservation efforts by offering insights into sustainable forest management practices that can help protect and preserve these valuable ecosystems.

## 2. Material and Methods

The study focuses on Georgia's forest ecosystems, with a particular emphasis on the Ajara region. The data on forest cover and biodiversity was derived from the National Forest Census of Georgia conducted in 2023. This census provided comprehensive information on the total forest area, species composition, forest health, and the distribution of forests across various elevation zones.

In addition to data from the National Forest Census, this study draws upon botanical surveys and field observations to document the presence of key species in Ajara's forests. The vertical zonation of vegetation was analyzed to understand the distribution of species across different altitudinal gradients. Special attention was given to the impact of pests, pathogens, and climate change on forest health, as well as to the management practices employed to address these challenges.

The analysis also includes an examination of forest restoration efforts, pest management strategies, and the role of natural regeneration in maintaining the health and sustainability of Georgia's forests.

## 3. Results and Discussion

### 3.1 Floral Diversity and Relic Species of Georgia's Forests

Georgia's forests boast a remarkable variety of plant life, with up to 5,000 species of wild and feral plants, including both angiosperms and gymnosperms. Additionally, the flora includes 8,300 species of spore-bearing plants, such as around 75 fern species, 600 species of moss (Bryophyta sensu stricto), 600 species of lichens, 5,000 species of fungi, and up to 2,000 species of algae. Many of these species are relics from the Tertiary period, which, while unable to form large independent ecosystems, thrive in mixed groves dominated by various woody species. These groves, where individual species appear as separate biogroups, reveal the immense biological diversity present in Georgia's forests (Gagnidze, 2000; Goginashvili et al., 2021).

The uniqueness of Ajara's flora is largely due to its role as a refuge during the Ice Age, specifically in the Southern Kolkheti region (Ajara and Guria), where many species were preserved. These species, some of which have centuries-old evolutionary histories, trace their origins back to the Oligocene period and evolved from the ancient Arcto-Terrician flora. The "Mediterranean-Turghai" flora, as termed by Grosheim (1948), consisted of both deciduous and coniferous species, from which many modern species evolved through natural selection and adaptation.

Key relic species from this evolutionary process, now known as Tertiary relics, include: *Rhododendron ponticum (L.), Rhododendron ungernii (Trautv.), Laurocerasus officinalis (Roem.), Taxus baccata (L.), Laurus nobilis (L.), Buxus colchica (P.), Epigaea gaultherioides (Boiss.), Pterocarya pterocarpa (Michx.), Zelkova carpinifolia (Pall.), Acer velutinum (Boiss.), Castanea sativa (Mill.), Juglans regia (L.), Quercus pontica (Koch.), Betula medwedewii (Regel.), Rhamnus imeretina (Booth.), Fraxinus excelsior (L.), Tilia caucasica (Rupr.), Acer campestre (L.), Vaccinium arctostaphylos (L.), Phillyrea vilmoriniana (Boiss.), Arbutus andrachne (L.), Diospyros lotus (L.), Staphylea pinnata (L.), Staphylea colchica (Steven), Juniperus foetidissima (Willd.).*

These relic species form the foundation of Ajara's unique flora and contribute to its ecological richness. Over time, this diversity has shaped the distinct biological landscape of the region, further establishing Ajara as a critical area for biodiversity conservation.

### 3.2 Forest Cover and Vegetation Zonation in Georgia

According to the 2023 National Forest Census of Georgia, the country's total area of forests and forest lands covers approximately 3,420,400 hectares. Of this, 3,100,500 hectares are specifically covered by woody plants that constitute forests, accounting for 44.5% of the total land area of the country. Among the various regions, Ajara stands out with an exceptionally high forest cover rate of 68.9%, a figure that significantly surpasses the global average of 27% and the 15% forest cover seen in Georgia's neighboring countries. This substantial forest coverage places Georgia among the most forest-rich countries in Europe.

The diversity of Georgia's forests is remarkable, with over 400 woody species represented in the form of trees or shrubs. These species belong to 123 botanical genera and 56 families, and they are distributed across a wide range of elevations, from the seacoast up to altitudes of 2,900–3,000 meters. More than 60% of the forested area lies above 1,000 meters above sea level. Additionally, a significant portion of the forests (over 49%) is located on slopes with gradients of 26° to 35°, while 39% of the forests are spread on north-facing slopes.

Unlike other regions of the world that experience arid or semi-arid conditions, western Georgia is characterized by the absence of these vegetation belts. In this region, forests cover the plains and slopes from sea level, creating a lush and diverse landscape.

The vertical zonation of Georgia's vegetation is well-defined and is divided into several belts. In western Georgia, this zonation is relatively simple and is composed of five main belts, as described by D. Manjavidze (1965) and R. Kvachakidze (1996):

- Mixed subtropical forests, which extend up to 500-600 meters,
- Forests, which reach up to 1,900-2,000 meters,
- Subalpine zones, extending from 1,900 to 2,500 meters,
- Alpine zones, reaching 2,500 to 3,100 meters,
- Nival zones, located above 3,100 meters.

In eastern Georgia, the vertical zonation is more complex, with six distinct vegetation zones (Zazanashvili et al., 1995):

- Semi-deserts, dry steppes, and arid sparse forests (150-600 meters),
- Forest zones (600-1,900 meters),
- Subalpine zones (1,900-2,500 meters),
- Alpine zones (2,500-3,000 meters),
- Subnival zones (above 3,000 meters),
- Nival zones (above 3,500 meters).

This clear vertical stratification plays a crucial role in shaping the biodiversity and distribution of plant species across Georgia's diverse landscapes.

### 3.3 Forest Categories and Composition within Georgia's State Forest Fund

Georgia's forests, as reported in the 2023 National Forest Census, encompass a total area of 3,420,400 hectares, with the State Forest Fund being divided into two principal categories: Protected Areas and the State Agricultural Forest Fund. Together, these categories play a crucial role in the preservation of Georgia's rich biodiversity, as well as in the sustainable use of its forest resources.

Protected Areas make up a significant part of the forested landscape, covering 312.9 thousand hectares, which accounts for 10.4% of the total forest area. Within this category, the most important sub-regions include State Reserves, which span 136.6 thousand hectares (4.6%), and National Parks, covering 134.8 thousand hectares (4.5%). Other protected zones, such as natural monuments, forbidden areas, and protected landscapes, though smaller in size, collectively represent areas of high conservation value. These areas are vital in safeguarding unique ecosystems and species, ensuring that key habitats remain undisturbed.

In contrast, the State Agricultural Forest Fund occupies the largest portion of Georgia's forests, covering an extensive 2,694.7 thousand hectares or 89.6% of the total forested land. This category is further subdivided into resort forests (4%), green zone forests (9.2%), and soil protection and water regulation forests, which make up the bulk of this category at 76.4%. These forests are not only significant for their economic value but also for their role in protecting soil integrity and regulating water systems, particularly in Georgia's mountainous regions.

The composition of Georgia's forests is notably diverse, with deciduous trees dominating the landscape, accounting for 79.8% of the total forested area, while coniferous trees cover the remaining 20.2%. Among the deciduous species, beech stands out as the most prevalent, both in terms of the area it covers and the wood resources it provides. Additionally, a remarkable 95% of Georgia's forests are of natural origin, reflecting ecosystems that have evolved with minimal human intervention. These natural groves exhibit a wide range of compositions and structures, from dense forests to more open, mixed groves, further contributing to the country's biodiversity.

Within these forests, the undergrowth is rich in both evergreen and deciduous shrubs, along with a variety of broad-leaved and herbaceous plants. Notably, 90% of the undergrowth species are known for their medicinal properties, which add a layer of ecological and economic value. Key species in this regard include fruit-bearing trees such as Juglans *mandshurica* and *Juglans regia* (walnuts), *Castanea sativa* (sweet chestnut), and various species of *Vaccinium, Ribes,* and *Rubus.* These plants not only contribute to the biodiversity of Georgia's forests but also play an essential role in supporting local economies through the harvesting of fruits and other valuable products.

A large proportion of Georgia's forests (97.7%) are located on medium to steep slopes, where they perform critical environmental functions, particularly soil protection and water regulation. These forests, spread across challenging terrains, are instrumental in preventing soil erosion and managing water resources. In terms of forest moisture classification, the largest areas are found in groves categorized under moisture class III (40-59.9) and moisture class VI (≥100), which are characterized by higher moisture retention and greater biodiversity. In terms of density, forests with low frequency (0.3-0.4) account for 17.4% of the total area, average frequency (0.5-0.7) forests occupy the majority with 79.2%, and forests with high frequency (0.8-1.0) represent 3.4% of the forested landscape.

The unique characteristics of the Ajara floristic region have earned it global recognition. The International Union for Conservation of Nature (IUCN) has designated Ajara as one of the 34 biodiversity hotspots in the world, a recognition that underscores the region's exceptional biological diversity and the critical importance of its conservation. These hotspots are identified as areas where the greatest variety of species, particularly endangered species, are concentrated. Furthermore, Ajara is included in the list of 25 global regions recognized for their unique levels of biodiversity, making it a priority for both national and international conservation efforts. This designation highlights the necessity of ongoing protection and sustainable management to preserve Ajara's diverse ecosystems for future generations.

### 3.4 Timber Stock and Forest Health in Georgia

The average timber stock in Georgia's forests is estimated at 231.8 $m^3$ per hectare. This stock includes both growing timber from single trees and non-growing timber such as dried wood (7 $m^3$/ha) and broken wood (7.2 $m^3$/ha). In total, the volume of timber in Georgian forests amounts to 528.2 $m^3$ per hectare. Additionally, the timber increment—or the rate of growth—is noteworthy, averaging 6 $m^3$/ha annually, which contributes to the forest's overall annual growth of 13.7 million $m^3$. Georgia's forests are predominantly mountainous, with 85% of the forest area situated in high-altitude regions, and 73% of these forests occur on slopes above 1,000 meters. The annual growth of timber stock amounts to approximately 4.5 million $m^3$, providing a valuable resource for the country's forestry industry. Natural forests, which cover 680.7 thousand hectares (22.6% of the country's forested area), make up a significant portion of this growth. However, 642.1 thousand hectares of Georgia's forest land are currently in temporarily occupied territories, such as Abkhazia, where natural forests cover 507.1 thousand hectares (with 479.9 thousand hectares under forest cover) and an additional 173.6 thousand hectares in other areas, with 162.2 thousand hectares being forested (First National Forest Inventory of Georgia, 2023).

### 3.5 Impact of Pests and Diseases on Georgian Forests

The overall health of Georgia's forests, while seemingly stable based on forestry tax indicators, has been significantly affected by long-term biotic and abiotic factors. In particular, climate change has led to rising temperatures, which have contributed to the proliferation of pests and diseases on an unprecedented scale. The rapid spread of these pest diseases is unlike anything previously recorded in the forest history of Georgia, and the consequences are profound, with certain areas of forest ecosystems destroyed and several species facing the threat of extinction.

One notable example is the decline of the evergreen Colchian larch, which has been severely impacted by the pathogenic fungus *Cylindrocladium buxicola*, causing widespread weakening and dieback of this species. Similarly, boxwood species in Georgia have been affected by a combination of bacteria, soil fungi, and sterile fungal mycelium, resulting in widespread wilting.

The greatest damage to Georgian boxwood has been caused by the invasive insect *Cydalima perspectalis,* which has led to the withering of 90% of the boxwood population in Georgia.
Among the pests affecting *Picea Orientalis*, several species require continuous monitoring due to their destructive impact, including: *Ips typographus L., Ips acuminatus Eichn., Dendroctonus micans Kugel., Ips sexdentatus Boern., Pytiogenes bidentatus Fabr., Pytiogenes quadridens Hert*. (Vasadze et al., 2022; Vasadze et al., 2023; Beridze et al., 2024)

The decline in the sanitary condition of eastern spruce forests often results not only from these primary pests but also from a suite of secondary trunk pests, such as: *Pityocteines curvidens Cerm,. Pityocteines spinidens Reitt., Cryphalus abietis Ratz., Cryphalus pussilus Cyll., Pityogenes bidentatus Hrbst., Pityogenes quadridens Hrbst., Pityogenes chalgographus L., Crypturgus cinereus Hrbst., Trypodendron lineatum Oliv., Hylugrops palliatus Gyll., Blastophagus piniperda L., Anisandrus dispar F., Orthotomicus suturalis Gyll., Orthotomicus proximus Eichh., Dryocoetes autographus Eichh., Pityophthorus pityographus Ratz., Monochamus galloprovincialis Oliv., Monochamus sutor L., Pogonocherus caucasicus Cill., Morimus verecundus Fald., Tetropium castaneum L., Tetropium fuscum F., Rhagium inquisitor stshukini Sem., Rhagium inquisitor L., Rhagium mordax Dg., Callidium violaceum L., Pissodes pini caucasicus Roub., Pissodes harciniae Hrbst., Pissodes piniphilus Hrbst., Sirex argonautarum Sem., Paururus juvencus L., Dioryctria splendidella* (Vasadze et al., 2024).

The situation in Chestnut Grove is similarly dire. The European chestnut *(Castanea sativa Mill.),* an important species for both biodiversity and the economy, is suffering from chestnut blight caused by the fungus *Cryphonectria parasitica* (Dumbadze et al., 2018, Vasadze et al., 2022). This disease has resulted in both group-focal and scattered wilting across large areas of chestnut groves. Similarly, the elm species (*Ulmus glabra Huds*.) are being affected by the *Ophiostroma ulmi* fungus, further degrading the health of the forests.

Biological control measures, such as inoculation of diseased chestnut trees with specific strains, have shown promising results in halting the spread of *Cryphonectria parasitica* in affected chestnut groves. Additionally, a combination of integrated pest management strategies, including the use of pheromone traps, the placement of insect-catching trees, and the breeding of entomophagous insects in laboratory conditions have been employed to reduce pest populations. Forest management practices also include sanitary cutting, thinning, and the removal of waste trees to restore the health and resilience of affected forest areas. These comprehensive efforts aim to mitigate the damage caused by pests and diseases and ensure the long-term sustainability of Georgia's valuable forest ecosystems.

### 3.6 Integrated Pest Management Strategies

In response to the growing threat posed by pest infestations, Georgia has implemented a series of Integrated Pest Management (IPM) strategies aimed at controlling and reducing the spread of harmful species. These strategies focus on both monitoring and controlling pest populations through a combination of biological, mechanical, and chemical methods.

One key method in these efforts is the use of pheromone traps, which help monitor and manage populations of bark beetles, particularly in spruce forests. By attracting and capturing pests like *Ips typographus* and *Dendroctonus micans*, pheromone traps offer an effective way to control infestations before they reach destructive levels.

Biological control methods have also been instrumental in reducing pest populations. One successful example is the introduction of the predatory beetle *Rhizophagus grandis*, which has proven effective in controlling *Dendroctonus micans* populations. This natural predator helps keep harmful beetle populations in check, reducing the need for chemical interventions (Vasadze et al., 2024; Beridze et al, 2024).

Sanitary cutting—the selective removal of infected and dead trees—has been another critical measure in maintaining forest health. Between 2013 and 2023, over 700,000 cubic meters of timber were harvested through sanitary cuts (Table 1). This proactive approach has helped limit the spread of pests and diseases by removing weakened trees that could otherwise act as breeding grounds for insects and pathogens.

However, the ongoing impacts of climate change, including rising temperatures and shifting precipitation patterns, are expected to exacerbate pest outbreaks in the coming years. These environmental changes may increase pest proliferation, making continued investment in IPM strategies essential to safeguarding Georgia's forests. Integrating advanced monitoring technologies and proactive forest management will be critical in combating the challenges posed by both existing and emerging threats (Gokturk et al. 2022).

Table 1. Volume of Firewood and Timber Cut (2013-2023)

| Year | Timber ($m^3$) | Firewood ($m^3$) | Total ($m^3$) |
|---|---|---|---|
| 2013 | 5,395 | 70,499 | 75,894 |
| 2014 | 5,125 | 72,856 | 77,981 |
| 2015 | 4,726 | 70,784 | 75,510 |
| 2016 | 4,409 | 61,013 | 65,422 |
| 2017 | 6,749 | 62,285 | 69,034 |
| 2018 | 8,710 | 49,921 | 58,631 |
| 2019 | 4,451 | 54,039 | 58,490 |
| 2020 | 5,989 | 52,839 | 58,828 |
| 2021 | 5,951 | 46,858 | 52,809 |
| 2022 | 5,298 | 54,677 | 59,975 |
| 2023 | 5,342 | 50,205 | 55,547 |

From 2013 to 2023, the volume of timber and firewood cut in Georgia's forests exhibited significant fluctuations. The peak in wood extraction in 2014, driven largely by firewood demand, marks a period of intense forest utilization. However, a notable decline in wood cutting occurred from 2015 to 2016, suggesting a shift towards more conservative forest management practices, possibly in response to increasing pest infestations and the need for forest conservation.

The sharp increase in timber cutting in 2018 reflects a targeted intervention, likely involving sanitary cutting to remove diseased or pest-infested trees. This period aligns with the spread of invasive species like *Ips typographus L.*, *Dendroctonus micans Kugel.*, *Ips sexdentatus Boern.*, Cryphonectria parasitica, and so on, which led to widespread damage in key tree species, necessitating the removal of affected trees.

The relatively steady extraction levels from 2020 onwards indicate stabilization in forest management practices. While pest control measures have helped mitigate the damage, the data suggest that continued monitoring and climate-adaptive management are crucial to sustaining Georgia's forests amidst ongoing ecological challenges (Table 1).

## 4. Conclusion and Suggestions

Georgia's forests are vital to global biodiversity, serving as habitats for rare species and providing essential ecosystem services. Despite their ecological significance, these forests are under significant threat from pests and diseases. The impacts of climate change, characterized by increasing temperatures and shifts in precipitation patterns, have intensified these challenges by fostering conditions conducive to pest outbreaks and diminishing the natural resilience of forest ecosystems.

Integrated pest management (IPM) strategies, including the use of biological control agents, pheromone traps, and sanitary cutting, have shown success in mitigating pest damage and preserving forest health. However, with the accelerating impact of climate change, forest management practices must continue to evolve. Continuous monitoring, research, and the development of climate-resilient practices are essential to ensure the long-term protection of Georgia's forests.

To better safeguard Georgia's forests against future threats, several key strategies should be prioritized:
Enhancing Pest Monitoring Systems: Leveraging advanced technologies for pest monitoring can significantly improve the accuracy and timeliness of responses to infestations. Real-time data collection and predictive modeling tools can enable more effective interventions, helping to reduce the severity of pest outbreaks before they cause widespread damage.

Strengthening Biological Control Methods: Enhancing biological control methods is essential for sustainable forest management. The introduction and research of new biological control agents, particularly those well-suited to Georgia's unique forest ecosystems, can offer more environmentally friendly and long-lasting solutions for managing pest populations without relying on chemical interventions.

Implementing Climate-Resilient Forest Management: Forest management practices must be adapted to cope with the stressors of climate change. Afforestation programs that prioritize pest-resistant species and strategies designed to increase the forests' adaptive capacity in the face of drought and temperature rise are crucial for ensuring long-term forest health and stability.

Fostering International Collaboration: Addressing these challenges will require continued international collaboration. Partnerships between Georgian forestry institutions, academia, and international organizations will facilitate knowledge exchange, resource sharing, and the development of effective pest control and forest management practices. These collaborations will be instrumental in implementing sustainable management solutions at scale.

Involving Local Communities: Engaging local communities in forest management through education and participatory initiatives can bolster conservation efforts. Public awareness campaigns that emphasize the ecological importance of healthy forests and promote sustainable forest use at the community level are critical for ensuring long-term conservation. Empowering local populations to take an active role in forest protection will strengthen both ecological and social resilience.

In conclusion, the successful protection of Georgia's forests requires a multifaceted approach that integrates cutting-edge technologies, climate-adaptive strategies, and community involvement. By continuing to innovate and collaborate, Georgia can effectively confront the ongoing threats posed by pests and climate change, ensuring the sustainability of its forests for future generations.

## 5. References

Beridze M., Dumbadze G., Gokturk T., Vasadze R. 2024. Current Status of Bark Beetles Distribution and Identification in Georgia-Turkey Border Area. Afr.J.Bio.Sc. 6(11):1711-1721.

Dumbadze G., Gokturk T., Vasadze R., Lomtatidze N., Chakhvadze Kh. 2018. Intensity of Chestnut Drying and Natural Restoration of the Forest in Keda Municipality (Ajara, Georgia). International Journal of Ecosystems and Ecology Science, 8(2): 347-352.

Gagnidze R. 2000. Diversity of Georgian flora. WWF Global, Tbilisi. pp 21-32.

Goginashvili, N., Togonidze, N., Tvauri, me., Manvelidze, Z., Memiadze, N., Zerbe, S., Asanidze, Z. 2021. Diversity and degradation of the vegetation of mountain belt forests of central Adjara (the Lesser Caucasus), Georgia. J. For. Sci, 67: 219–241

Gokturk, G Dumbadze, L Jgenti, R Vasadze. 2022. The Effects Of Global Warming On Insects. International Scientific Conference "Modern Problems of Ecology" 8: 44-54.

First National Forest Inventory of Georgia. Report. 2023. Enabling the Implementation of Georgia's Forest Sector Reform - ECO.Georgia. Tbilisi.

Ketskhoveli, N. 1959. Flora of Georgia. Tbilisi: Academy of Sciences of the Georgian SSR.

Kvachakidze R. 2010. Geobotanical regions of Georgia. Tbilisi, Science, 176 p.

Manjavidze D. 1982. Relic forests of Ajara and their national and economic importance. Metsniereba, Tbilisi. 262 p.

Vasadze R., Mamuladze M., Vasadze Z. 2023. Some Biological Features of the Crustagean Typographer. International Journal of Advanced Research, 11(06):255-267.

Vasadze R, Vasadze Z. 2024. Causes of the general sanitary impact of combinations of dark coniferous trees and dynamics of forest assessment indicators according to forest types. Batumi, Georgia. 223 p.

Vasadze R., Dumbadze G., Gokturk T., Chachkhiani-Anasashvili N. 2022. The biological characteristics of *Ips typographus* in Adjara spruce forests. 4th International Forest Entomology and Pathology Symposium (ENFITO 2022). 12-15 May, Trabzon, Turkey.

Zazanashvili N., Gagnidze R., Nakhutsrishvili G. 1995. The high mountain on the new vegetation map of Georgia. Journal of Vegetation Science, 6(1): 157-158.

# An Evaluation of Diameter Measurement Techniques: Comparing Calipers, Laser Devices, and the Measure Application

**Ensar Tuğralp Kanmaz, Emre Kilinçarslan*, Burhan Gencal**

Bursa Technical University, Faculty of Forestry, Forest Engineering Dept., Bursa, Türkiye
*emre.kilincarslan@btu.edu.tr

## Abstract

Forest management necessitates precise measurement of stand volume, traditionally achieved through volume tables and direct diameter measurements at breast height (DBH). However, these conventional methods are often time-consuming and costly, particularly in dense vegetation or challenging terrains. This study evaluates the efficacy of smartphone applications as an alternative to traditional methods and laser devices in forest inventory tasks. Measurements were conducted on four tree species (*Pinus nigra*, *Pinus sylvestris*, *Quercus cerris*, and *Fagus orientalis*) within the Bursa Forest District using calipers, laser device, and smartphone application (Measure). Results indicate that smartphone applications offer significant time savings and comparable accuracy to traditional methods, with an average measurement time of 2-3 seconds and minimal deviation. Laser measurements, while accurate, demonstrated longer durations and greater variability. Statistical analyses confirmed significant differences in measurement accuracy and duration based on method and distance. This study concludes that smartphone applications provide a practical, cost-effective, and efficient alternative for forest inventory measurements, promoting broader adoption of digital technologies in forestry practices.

***Keywords:*** *Diameter at breast height, measure application, laser meters, mobile phone, caliper*

## 1. Introduction

Effective forest management relies heavily on accurate assessments of stand volume, which are fundamental for creating forest management plans and determining timber yields. One of the key measurements required for these assessments is the diameter at breast height (DBH), which, combined with tree height, allows for the estimation of tree volume. Volume tables, often used in forest inventory tasks, are typically generated based on these measurements (Kalıpsız, 1984; Saraçoğlu, 1988). While these traditional methods are widely accepted, they can be time-consuming, labor-intensive, and challenging to implement in dense forests or difficult terrains, leading to a demand for more efficient and cost-effective alternatives (Yavuz and Saraçoğlu, 1999).

Recent advances in digital technology have introduced new tools and methods for improving the efficiency and accuracy of forest inventory processes. Photogrammetry-based systems and camera-based measurement tools have been increasingly explored as alternatives to manual measurement techniques. These systems often combine digital cameras with laser devices, enabling precise measurements of tree attributes, such as DBH and tree height, with significant time and cost savings (Varjo et al., 2006; Melkas et al., 2008; Vastaranta et al., 2009; Liang et al., 2014). In Japan, for instance, studies have shown that smartphones, such as the iPhone, can be effectively used to measure tree heights, with results comparable to traditional methods (Itoh et al., 2010). Similarly, research conducted in Türkiye has confirmed the potential of smartphones for measuring DBH, suggesting that these devices can be used as a valid alternative to more conventional tools (Ucar et al., 2022).

As the forestry sector increasingly embraces digital technologies, smartphone applications have emerged as promising tools for forest inventory tasks. These applications offer portability, ease of use, and accessibility, making them attractive alternatives to calipers and laser devices. The growing body of research highlights the potential for smartphone applications to improve efficiency in measuring forest stand attributes, particularly in challenging field conditions (Fan et al., 2019). However, while the use of smartphones for tree measurements has been explored in various studies, there is still a need for comprehensive evaluations comparing their accuracy, time efficiency, and usability against traditional measurement methods.

The primary goal of this study is to evaluate the effectiveness of smartphone applications in measuring DBH, comparing their performance with traditional calipers and laser devices across different tree species. Specifically, this study focuses on four common species in the Bursa Forest District: *Pinus nigra*, *Pinus sylvestris*, *Quercus cerris*, and *Fagus orientalis*. By analyzing the measurement accuracy and time required for each method, this research aims to determine whether smartphone applications can provide a practical, cost-effective alternative for forest inventory tasks. Ultimately, the study seeks to promote the broader adoption of digital technologies in forestry, contributing to more efficient and modernized forest management practices.

## 2. Material and Methods

The study was conducted within the boundaries of the Bursa Forest District Directorate (Figure 1), where suitable forest stands were selected for measurement. Four tree species were chosen for this research: *Pinus nigra* (black pine), *Pinus sylvestris* (Scots pine), *Quercus cerris* (Turkey oak), and *Fagus orientalis* (oriental beech). These species were selected based on their prevalence in the region and their varied bark structure, shape, and color, which may influence the measurement accuracy. To assess the effect of canopy closure on measurement accuracy, sample plots of 400, 600, and 800 m² were established based on the density of the forest stands. Smartphone applications were used in the measurements, the fieldwork was carried out during daylight hours, between 08:00 and 16:00, to maximize the smartphone camera's ability to detect tree objects under optimal lighting conditions.

Figure 1. Borders of Regional Directorate of Bursa

Two broadleaf species and two coniferous species were chosen to examine whether the bark texture, shape, and color of different tree types affect the measurement results. This diversity in species allowed for a comprehensive analysis of potential variables influencing the accuracy of smartphone-based and laser-based measurements.

The study involved both direct and indirect measurement methods. DBH measurements were conducted using three distinct techniques: calipers for direct measurements, and indirect measurements with both a smartphone application and a laser device. The laser measurements were performed using a Leica-Disto device, known for its precision in forestry applications (Figure 2). For smartphone-based measurements, the "Measure" application was used, which allows for indirect measurements by estimating the size of objects. The application automatically detects the dimensions of rectangular objects and provides users with the ability to capture and save an image of the measured object for verification purposes.


Figure 2. Instruments used for the measurements

In this study, a laser rangefinder was actively used to measure the crown diameters of trees. The sample plot sizes were determined based on canopy closure, with plots of 800 $m^2$ (r = 15.96 m) for low-density stands (11-40% closure), 600 $m^2$ (r = 13.82 m) for medium density stands (41-70% closure), and 400 $m^2$ (r = 11.28 m) for high-density stands (71-100% closure). The sample plots were circular, and the plot area was calculated using the formula for the area of a circle ($\pi r^2$). A stake was driven into the center of each plot, and the plot boundaries were determined by measuring the radius (r) with a tape measure. The selected sample plots contained at least 30 trees to ensure statistically valid results.

To standardize the DBH measurements across all methods, each tree within the sample plots was marked at 1.30 m height using a measuring tape, ensuring that all measurements (both direct and indirect) were taken from the same height on the tree (Figure 3). This was done to minimize discrepancies between the three methods being compared. The tape measure was also used to accurately determine the 1.30 m height for the placement of the measuring band on each tree.

Each tree species was assigned a separate sample plot, and within each plot, nine measurements were taken for each tree. The instruments used for the measurements included a laser rangefinder, a smartphone application, and a caliper, as shown in Figure 3. Indirect measurements using the laser and smartphone application were performed from four different distances: 0.5 m, 1 m, 1.5 m, and 2 m. These measurements were then compared to the direct caliper measurements. Given that each sample plot contained at least 30 trees, approximately 270 measurements were taken per tree species, resulting in a total of 1,080 measurements across the four tree species.

Figure 3. DBH measurement by Measure application

The rationale behind performing indirect measurements from varying distances (0.5 m, 1 m, 1.5 m, and 2 m) was to assess the impact of distance on the accuracy of the measurements. By conducting measurements at different distances with both the smartphone application and the laser device, the most accurate distance for DBH measurements was also determined.

Although indirect measurements were performed with centimeter-level precision, the smartphone application displayed the measurements as whole numbers. Therefore, all measurements were rounded to the nearest whole number for consistency. A laser rangefinder was used to measure the distance between the observer and the tree during indirect measurements. To determine the efficiency of each method, the time taken for each direct and indirect measurement was recorded using a stopwatch. This allowed for the comparison of the speed and ease of use for each method.

In the sample plots, the first tree to be measured was selected randomly, and subsequent trees were measured in a clockwise direction. To avoid confusion during subsequent measurements, each tree was numbered using spray paint. The deviation between the measurement methods for each tree was calculated using the formula shown in Equation 1:

$$Dev_{nmt} = d_{nkt} - d_{nmt}$$

$Dev_{nmt}$ represents the deviation between different measurement methods for each tree, $d_{nkt}$ is the DBH measured directly using the caliper for each tree, $d_{nmt}$ is the DBH measured indirectly using the laser rangefinder or the Measure application for each tree.

To statistically analyze the data and determine the differences between the methods, an analysis of variance (ANOVA) was conducted. ANOVA is a well-known and frequently used method for comparing the means of two or more groups to determine if at least one group mean is statistically different from the others (Moder, 2010; Allen, 2017). The effects of factors such as distance, dendrometric measurements, and tree species were analyzed using IBM SPSS software (IBM Corp., 2020). Before conducting the statistical tests, the normality of the data was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests, and the homogeneity of variances was evaluated with Levene's test. Post-hoc tests were also performed to identify which data sets differed significantly from the reference values.

This methodology facilitated a comprehensive comparison of the three measurement techniques—calipers, a smartphone application, and a laser device—in terms of both accuracy and efficiency. Direct caliper measurements served as the baseline for evaluating the performance of the smartphone and laser-based methods. Additionally, the smartphone application's ability to capture images provided visual validation, adding an extra layer of data accuracy. The study was designed to not only assess the precision of these modern digital tools but also to examine their practical applications across different tree species, elevations, and canopy densities. The combination of direct and indirect measurement approaches, alongside statistical analyses, enabled a thorough investigation of the impact of distance and tree species on measurement results, with the goal of determining the most effective and efficient method for forest inventory practices.

## 3. Results and Discussion

The descriptive statistics for the measured trees provide an overview of the variability in diameter at breast height (DBH) across the four species (Table 1). *Pinus sylvestris* exhibited the largest average DBH at 30.91 cm, with a maximum of 50.8 cm and a minimum of 8.9 cm, indicating a broad range of tree sizes. In contrast, *Pinus nigra* showed a more uniform distribution, with a mean DBH of 21.69 cm and a narrower range between the minimum (12.8 cm) and maximum (32.8 cm) values.

Table 1. Descriptive statistics of tree species at breast height (DBH)

| Species | DBH | | |
|---|---|---|---|
| | Mean | Max | Min |
| *Pinus nigra* | 21,69 | 32,80 | 12,8 |
| *Pinus sylvestris* | 30,91 | 50,8 | 8,9 |
| *Quercus cerris* | 23,38 | 39,1 | 10,9 |
| *Fagus orientalis* | 21,89 | 32,9 | 12,6 |

Broadleaf species, such as *Quercus cerris* and *Fagus orientalis*, had similar average DBH values (23.38 cm and 21.89 cm, respectively), but *Quercus cerris* demonstrated a wider range, with a maximum of 39.1 cm. The variability in DBH across species suggests differences in growth conditions and tree characteristics, which could impact the performance of the measurement methods tested.

The comparison of DBH measurements across different methods and tree species is summarized in Table 2. The direct caliper measurements, considered the baseline, show the highest average DBH values across all species. Pinus sylvestris had the largest mean DBH (30.91 cm) with the greatest standard deviation (7.96 cm), indicating more variability in tree sizes. In contrast, Pinus nigra exhibited a more uniform DBH distribution with a mean of 21.69 cm and a standard deviation of 4.14 cm.

Indirect measurements using the Measure application generally produced results close to the caliper measurements, particularly at distances of 150 cm and 200 cm. For instance, the DBH values for Fagus orientalis at 150 cm and 200 cm were 22.33 cm and 22.13 cm, respectively, which were close to the caliper measurement of 21.89 cm. However, at shorter distances (50 cm and 100 cm), the Measure application tended to slightly underestimate the DBH for most species.

Table 2. Comparison of DBH measurements across different methods and tree species

| Ölçüm tekniği | Karaçam | | Sarıçam | | Saçlı Meşe | | Kayın | |
|---|---|---|---|---|---|---|---|---|
| | Ortalama (cm) | Standart Sapma (cm) | Ortalama (cm) | Standart Sapma (cm) | Ortalama (cm) | Standart Sapma (cm) | Ortalama (cm) | Standart Sapma (cm) |
| Çap Ölçer | 21,69 | 4,14 | 30,91 | 7,96 | 23,38 | 6,43 | 21,89 | 4,29 |
| Measure 50 cm | 20,57 | 3,44 | 29,70 | 7,89 | 21,87 | 5,81 | 21,23 | 4,07 |
| Measure 100 cm | 20,40 | 3,25 | 29,80 | 7,80 | 22,47 | 6,08 | 21,97 | 4,46 |
| Measure 150 cm | 21,07 | 3,81 | 29,80 | 8,54 | 22,40 | 5,87 | 22,33 | 4,50 |
| Measure 200 cm | 21,43 | 4,27 | 30,40 | 8,16 | 22,53 | 5,73 | 22,13 | 4,34 |
| Lazer 50 cm | 18,45 | 3,01 | 26,96 | 8,40 | 20,01 | 4,69 | 18,82 | 3,38 |
| Lazer 100 cm | 20,72 | 3,10 | 28,80 | 6,73 | 21,45 | 4,94 | 20,21 | 3,48 |
| Lazer 150 cm | 22,35 | 5,04 | 29,96 | 7,65 | 23,24 | 5,84 | 21,28 | 4,35 |
| Lazer 200 cm | 20,88 | 5,37 | 29,64 | 8,34 | 21,49 | 5,77 | 21,07 | 4,26 |

The laser device measurements showed more variability, with larger deviations from the caliper measurements, particularly at closer distances. For instance, at 50 cm, the laser device underestimated DBH for Pinus sylvestris (26.96 cm) compared to the caliper measurement (30.91 cm). As the distance increased to 150 cm, the laser device measurements became more accurate, closely aligning with the caliper measurements.

Overall, the Measure application performed comparably well, especially at distances of 150 cm and 200 cm, while the laser device showed better performance at longer distances. The time required to perform DBH measurements using different techniques was compared across tree species, and the results are summarized in Table 3. The caliper method, which served as the baseline, took an average of 4.93 seconds for Pinus nigra and Fagus orientalis, with a slightly longer time of 5.87 seconds for Pinus sylvestris, reflecting the general uniformity in time requirements for this direct method.

Table 3. Comparison of DBH measurements time across different methods and tree species

| Ölçüm tekniği | Karaçam | | Sarıçam | | Saçlı Meşe | | Kayın | |
|---|---|---|---|---|---|---|---|---|
| | Ortalama (sn) | Standart Sapma (sn) | Ortalama (sn) | Standart Sapma (sn) | Ortalama (sn) | Standart Sapma (sn) | Ortalama (sn) | Standart Sapma (sn) |
| Çap Ölçer | 4,93 | 4,14 | 5,87 | 1,50 | 4,35 | 0,89 | 4,93 | 1,82 |
| Measure 50 cm | 3,95 | 0,41 | 2,87 | 0,75 | 4,14 | 1,12 | 3,86 | 0,28 |
| Measure 100 cm | 3,71 | 0,17 | 3,14 | 1,15 | 4,03 | 0,81 | 3,73 | 0,12 |
| Measure 150 cm | 3,58 | 0,26 | 2,89 | 0,81 | 3,90 | 0,73 | 3,57 | 0,14 |
| Measure 200 cm | 3,85 | 0,18 | 3,14 | 1,38 | 4,07 | 0,71 | 3,84 | 0,19 |
| Lazer 50 cm | 14,15 | 4,05 | 9,29 | 5,03 | 13,27 | 2,93 | 15,05 | 3,01 |
| Lazer 100 cm | 14,79 | 3,95 | 8,65 | 4,69 | 14,71 | 2,93 | 15,05 | 2,84 |
| Lazer 150 cm | 14,42 | 4,02 | 8,62 | 4,32 | 14,66 | 2,30 | 14,79 | 4,26 |
| Lazer 200 cm | 14,04 | 2,94 | 9,67 | 4,88 | 15,56 | 2,52 | 15,60 | 2,85 |

The Measure application consistently demonstrated faster measurement times compared to both the caliper and laser methods. At distances of 50 cm to 200 cm, the Measure application averaged between 2.87 and 4.14 seconds, with the shortest times observed at 150 cm. For example, the measurement time for Pinus sylvestris was 2.89 seconds at 150 cm, significantly faster than the caliper method. Across all species, the Measure application showed minimal variation in measurement times, indicating its efficiency and consistency regardless of distance. In contrast, the laser device method took significantly longer to perform measurements. The average time ranged from 8.62 seconds to 15.60 seconds, depending on the distance and species. For instance, Fagus orientalis measurements at 200 cm took an average of 15.60 seconds, nearly three times longer than the Measure application at the same distance. The standard deviation for the laser device also indicated greater variability in measurement times, particularly at shorter distances. Overall, the Measure application emerged as the most time-efficient tool, especially at distances of 150 cm, offering significant time savings over both the caliper and laser methods.

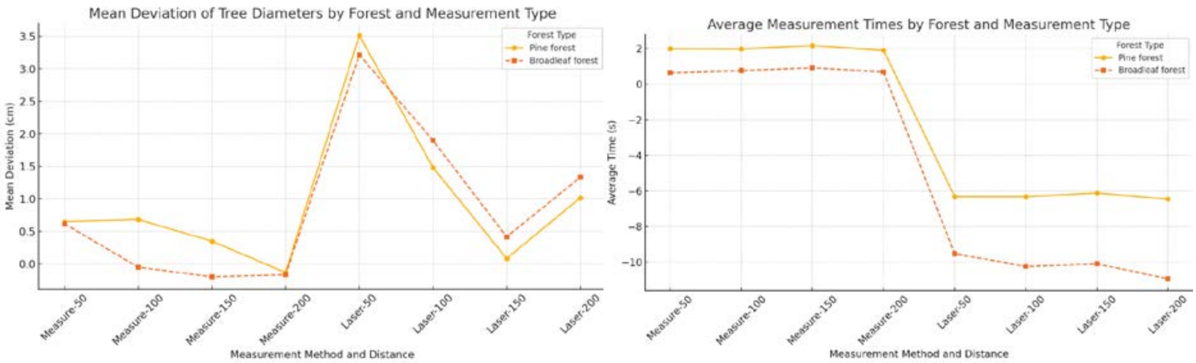



Figure 4. Comparison of measurement times and mean deviations by measurement method and forest type (Pine - Broadleaf)

Figure 4 compares the average measurement times and mean deviations for pine and broadleaf forests across different measurement methods and distances. The first graph demonstrates that the Measure application consistently produced faster measurement times compared to the laser method, with minimal variability across distances. Pine species generally showed slightly longer measurement times compared to broadleaf species. In contrast, the second graph shows the mean deviation in DBH measurements. For both forest types, deviations were minimal for the Measure method at 100 cm and 150 cm, while the laser method showed larger deviations, particularly at shorter distances (50 cm). This suggests that the Measure application provides more consistent and accurate results across various distances, especially for broadleaf species, which had less variability in measurement deviations compared to pine species.

### 3.1. Statistical Analysis

A one-way analysis of variance (ANOVA) was performed to compare the accuracy and efficiency of the three measurement methods—caliper, Measure application, and laser device—in terms of DBH values and measurement time. The results for DBH values (Table 4) indicated a significant difference between the methods, with an F value of 6.23 and a p value of 0.002. According to the Duncan post-hoc test, the caliper and Measure methods did not differ significantly in DBH measurements, with mean values of 23.98 cm and 23.75 cm, respectively. In contrast, the laser device produced significantly lower DBH values (mean: 22.35 cm), indicating that it consistently underestimated the tree diameters compared to the other methods.

These findings suggest that the Measure application is as accurate as the traditional caliper method, while the laser device shows a tendency to underestimate.

Table 4. One-Way ANOVA results for DBH measurements by method

| Parameter | Group | N | Duncan (Posthoc Test) $\bar{x}$ ± sd | CV | MS | df | KO | F | p |
|---|---|---|---|---|---|---|---|---|---|
| Method | Caliper | 120 | 23,98 ± 7,01[a] | Between | 562,04 | 2 | 281,02 | 6,23 | 0,002 |
| | Measure | 480 | 23,75 ± 6,72[a] | Within | 48533,19 | 1077 | 45,06 | | |
| | Lazer Meter | 480 | 22,35 ± 6,62[b] | Total | 49095,24 | 1079 | | | |
| | Total | 1080 | 23,15 ± 6,74 | | | | | | |

a, b: Groups that share the same letter do not have a significant difference between them

In terms of measurement time (Table 5), the ANOVA results revealed a highly significant difference between the methods, with an F value of 1297.91 and a p value of 0.00, indicating substantial variation in time efficiency. The Measure application was the fastest method, with an average time of 3.64 seconds, significantly lower than both the caliper (5.01 seconds) and laser device (13.27 seconds). The laser device required much more time on average, reflecting its lower efficiency in field applications. The Duncan post-hoc test confirmed that all three methods were significantly different from each other in terms of time, with the Measure application being the most time efficient.

Table 5. One-Way ANOVA results for DBH measurement time by method

| Parameter | Group | N | Duncan (Posthoc Test) $\bar{x}$ ± sd | CV | MS | df | KO | F | p |
|---|---|---|---|---|---|---|---|---|---|
| Method | Caliper | 120 | 5,01 ± 1,61[a] | Between | 23513,36 | 2 | 11756,68 | 1297,91 | 0,00 |
| | Measure | 480 | 3,64 ± 0,79[b] | Within | 9755,62 | 1077 | 9,05 | | |
| | Lazer Meter | 480 | 13,27 ± 4,36[c] | Total | 33268,98 | 1079 | | | |
| | Total | 1080 | 8,07 ± 5,55 | | | | | | |

a, b, c: Groups that share the same letter do not have a significant difference between them

A one-way analysis of variance (ANOVA) was conducted to examine the effect of distance on both DBH measurement accuracy and measurement time across different distances (Tables 6 and 7). DBH Measurement Accuracy by Distance (Table 6) revealed a statistically significant difference between groups, with an F value of 3.04 and a p value of 0.017. The Duncan post-hoc test showed that measurements taken at 0.5 meters (mean: 21.98 cm) had significantly lower DBH values compared to standard and larger distances (1.5 meters and 2 meters), which had mean values of 23.81 cm and 23.46 cm, respectively. This suggests that the accuracy of DBH measurements improves as the distance increases up to 1.5 meters, after which it stabilizes, aligning more closely with the standard method.

Table 6. One-way ANOVA results for DBH measurements by distance

| Parameter | Group | N | Duncan (Posthoc Test) $\bar{x}$ ± sd | CV | MS | df | KO | F | p |
|---|---|---|---|---|---|---|---|---|---|
| Distance | Standart | 120 | 23,98 ± 7,01[b] | Between | 549,44 | 4 | 137,36 | 3,04 | 0,017 |
| | 0.5m | 240 | 21,98 ± 6,62[a] | Within | 48545,79 | 1077 | 45,06 | | |
| | 1m | 240 | 22,97 ± 6,35a | Total | 49095,24 | 1079 | | | |
| | 1.5m | 240 | 23,81 ± 6,74[b] | | | | | | |
| | 2m | 240 | 23,46 ± 7,00[b] | | | | | | |
| | Total | 1080 | 23,15 ± 6,75 | | | | | | |

a, b: Groups that share the same letter do not have a significant difference between them

In terms of measurement time by distance (Table 7), the ANOVA results revealed a significant effect of distance on measurement time, with an F value of 10.81 and a p value of 0.00. The Duncan post-hoc test indicated that measurements at 0.5 meters and 1 meter took longer (mean times: 8.32 seconds and 8.47 seconds, respectively) compared to standard measurements (5.01 seconds). As the distance increased to 2 meters, the measurement time also increased slightly to 8.71 seconds. This pattern indicates that while closer distances can sometimes lead to longer measurement times, there is a threshold where time efficiency is compromised as the distance becomes larger.

Table 7. One-way ANOVA results for DBH measurement time by distance

| Parameter | Group | N | Duncan (Posthoc Test) $\bar{x}$ ± sd | CV | MS | df | KO | F | p |
|---|---|---|---|---|---|---|---|---|---|
| Distance | Standart | 120 | 5,01 ± 1,60[a] | Between | 1286,51 | 4 | 321,62 | 10,81 | 0,00 |
| | 0.5m | 240 | 8,32 ± 5,60[b] | Within | 31982,47 | 1075 | 29,75 | | |
| | 1m | 240 | 8,47 ± 5,81[b] | Total | 33268,98 | 1079 | | | |
| | 1.5m | 240 | 8,30 ± 5,75[a] | | | | | | |
| | 2m | 240 | 8,71 ± 5,83c | | | | | | |
| | Total | 1080 | 7,57 ± 5,55 | | | | | | |

a, b, c: Groups that share the same letter do not have a significant difference between them

## 4. Conclusion and Suggestions

The increasing prevalence and advancing technology of smartphones have made them indispensable tools in daily life, including in specialized fields like forestry. The Measure application has proven to be a highly efficient and accurate tool for DBH measurements in both broadleaf and coniferous forests. Its digital interface, ease of use, and fast measurement times make it a strong alternative to traditional methods like calipers. In comparison, laser devices demonstrated higher error rates and longer measurement times, particularly in broadleaf forests, suggesting that they require more careful alignment and additional attention to avoid measurement errors.

The findings of this study underscore the Measure application's reliability and time-saving potential, offering significant advantages in forest inventory tasks. With its low error margins and quick execution, it provides comparable accuracy to traditional caliper measurements while substantially reducing the time required. In contrast, laser devices, though useful, are less efficient and prone to higher variability in measurements, particularly over shorter distances.

Given these results, it is recommended to further integrate digital technologies, particularly smartphone applications like Measure, into future forest inventory and management practices. The efficiency and accuracy of such tools can lead to more cost-effective and faster inventory processes. However, when using laser devices, extra attention should be given to proper device alignment and reducing user errors, especially in denser forest environments. By adopting digital tools more widely, forestry professionals can achieve more reliable, consistent, and efficient measurement results, enhancing both the quality and speed of forest management operations.

**Acknowledgements**
This study was supported by the TÜBİTAK 2209-A Research Project Support Program. We would like to express our sincere gratitude to The Scientific and Technological Research Council of Türkiye (TÜBİTAK) for their financial support, which made this research possible.

**References**

Fan, G., Chen, F., Li, Y., Liu, B., Fan, X. 2019. Development and testing of a new ground measurement tool to assist in forest GIS surveys. Forests, 10(8): 643.

IBM Corp., 2020: IBM SPSS Statistics for Windows, Version 22.0. IBM Corp., Armonk, NY.

Itoh, T., Eizawa, J., Yano, N., Matsue, K., Naito, K. 2010. Development of software to measure tree heights on the smartphone. Journal of the Japanese Forest Society, 92(4): 221-225.

Kalıpsız, A. 1984. Dendrometri, İstanbul Üniversitesi Orman Fakültesi Yayınları, İ.Ü. Yayın No: 3194,

Liang, X., Jaakkola, A., Hyyppä, J., Kaartinen, H., Lehtomäki, M., Pyörälä, J. 2014. The use of a mobile laser scanning system for monitoring tree growth in forest stands. Remote Sensing, 6(7): 6589-6611.

Melkaş, T., Varjo, J., Vastaranta, M. 2008. Measuring tree diameters with digital cameras. Scandinavian Journal of Forest Research, 23(4): 276-285.

Moder, K., 2010. Alternatives to F-test in one way ANOVA in case of heterogeneity of variances (a simulation study). Psychological Test and Assessment Modeling, 52(4): p.343.

Saraçoğlu, E. 1988. Orman Envanteri ve Hacim Tabloları. Ankara Üniversitesi Basımevi, 1988: 112-119.

Ucar, Z., Değirmenci, A. S., Zengin, H., Bettinger, P. 2022. Evaluating the Accuracy of Remote Dendrometers in Tree Diameter Measurements at Breast Height. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering, 43(1): 185-197.

Varjo, J., Henttonen, H., Lappi, J., Heikkonen, J., Juujärvi, J. 2006. Digital horizontal tree measurements for forest inventory.

Vastaranta, M., Liang, X., Kankare, V., Kaartinen, H., Hyyppä, J., Holopainen, M. 2015. Smartphone applications for forest inventory measurements. Scandinavian Journal of Forest Research, 30(5): 456-465.

Yavuz, H., Saraçoğlu, N. 1999. Kızılağaç için Uyumlu ve Uyumsuz Gövde Çapı Modelleri, Turkısh Yayın No: 193, Kurtuluş Matbası, İstanbul, 359 s.

# The Potential of Mobile Applications in Stand Parameter Estimation and Time Analysis: A Case Study of the Arboreal Application

**Safa Ilikdere[1], Burhan Gencal[1*], Turan Sönmez[1], Emre Kilinçarslan[1], Johan Ekenstedt[2]**

[1]Bursa Technical University, Faculty of Forestry, Bursa, Türkiye
[2]Arboreal AB Company, CEO, Tavelsjö, Sweden
*burhan.gencal@btu.edu.tr

**Abstract**

This study evaluates the effectiveness of the Arboreal application, a digital tool for measuring tree dimensions, by comparing it with traditional manual measurement methods. Conducted within the Bursa Forest Regional Directorate, the research involved four tree species: two broad-leaved (*Fraxinus excelsior* and *Alnus glutinosa*) and two coniferous (*Pinus brutia* and *Abies nordmanniana*). Measurements were taken in 5 sample plots distributed across various locations for each tree species. The sample plots ranged from 400 to 800 square meters, depending on canopy closure. If a sample plot contained fewer than 30 trees, the area was expanded to allow for statistical analysis. In total, 600 trees were measured, and descriptive statistics were provided. Measurements were conducted outdoors during midday to maximize sunlight. The Arboreal application demonstrated significant advantages in both measurement accuracy and efficiency. Diameter measurements showed a standard deviation of 2.42 cm, while height measurements had a standard deviation of 2.32 m. The Root Mean Square Error (RMSE) for measurement times was 3.40 seconds less for diameter and 16.96 seconds less for height compared to traditional methods. Error analysis revealed an RMSE of 8.24% for diameter and 13.89% for height measurements. The percentage RMSE for measurement times was 68.30% for diameter and 60.40% for height. Significant differences were observed in diameter measurements for broad-leaved species and height measurements for coniferous species. These findings indicate that the Arboreal method provides superior accuracy and time efficiency over traditional techniques, making it a preferable choice for field studies to enhance measurement consistency and save time. Detailed analyses by tree species have also facilitated the identification of the most suitable measurement method for each species, contributing significantly to forest management and ecological research.

***Keywords:*** *Forestry technology, forest inventory, arboreal application, Diameter at Breast Height (DBH), tree height*

## 1. Introduction

Forests are vital ecosystems that provide essential resources for biodiversity and play a critical role in regulating global carbon and energy cycles (FAO, 2010). Accurate information about forest conditions is fundamental for making informed decisions regarding investments, policies, and forest management practices (Köhl, 2006). Among the essential measurements in forest inventories are tree height and diameter at breast height (DBH), which serve as key indicators for estimating tree volume, biomass, and overall forest growth (Loetsch et al., 1976; Van Laar et al., 2007). While remote sensing technologies can estimate tree height with reasonable accuracy, DBH and volume estimations often rely on direct field measurements, which remain time-consuming and labor-intensive (Köhl, 2006).

The growing use of mobile devices such as smartphones and tablets in forestry has introduced new possibilities for more efficient data collection. Mobile applications like Arboreal leverage smartphone sensors to measure tree dimensions, offering a practical alternative to traditional methods. These applications, when combined with technologies such as LiDAR and augmented reality (AR), have demonstrated the potential to improve the accuracy of tree measurements (Tatsumi et al., 2023). However, several studies have also highlighted challenges related to the reliability and precision of smartphone-based measurements, especially across different forest types and species (Tomaštík et al., 2017; Ficko, 2020; Uçar et al., 2022; Gülci et al., 2023).

In recent years, research on the use of mobile devices for forest measurement has increased significantly. Villasante and Fernandez (2014) found that smartphones like HTC Desire and Samsung Galaxy Note I produced measurements comparable to traditional tools such as Vertex and Blume Leiss. Bijak and Sarzyński (2015) also validated smartphones for DBH measurements, comparing them to Suunto hypsometers. More recent studies, such as those by Fan et al. (2019) and Wu et al. (2021), have continued to confirm the practicality and accuracy of mobile devices for forest measurements, particularly when enhanced with advanced sensing technologies like LiDAR and AR.

This study aims to evaluate the accuracy, precision, and time efficiency of the Arboreal mobile application for measuring tree height and DBH across different tree species and forest types. The primary objectives are to assess the app's accuracy with a target of 85% compared to traditional methods and to evaluate its time efficiency in relation to conventional tools. By focusing on these aspects, the study seeks to highlight the practical benefits of the Arboreal app for forest inventory and management, contributing to the broader understanding of how mobile applications can improve both measurement accuracy and operational efficiency in forestry practices.

## 2. Material and Methods

### 2.1. Study Area

The study was conducted in the Bursa Forest Regional Directorate, as shown in Figure 1, where two coniferous species (*Pinus brutia* and *Abies nordmanniana subsp. bornmuelleriana*) and two broad-leaved species (*Alnus glutinosa* and *Fraxinus excelsior*) were selected as representative tree species. For each species, five sample plots were chosen, with at least 30 trees per plot. The sample plots were selected across varying elevations and slopes to ensure a diverse range of conditions. Plot sizes were determined based on canopy closure and ranged from 400 to 800 square meters.


Figure 1. Borders of Regional Directorate of Bursa

## 2.2. Sample Plot Selection and Measurement Conditions

Fieldwork was conducted by the research team to identify suitable sample plots (Figure 2). The forest stands selected for the study are located within the boundaries of the Bursa Forest Regional Directorate, specifically in areas dominated by *Pinus brutia*, *Abies nordmanniana subsp. bornmuelleriana*, *Alnus glutinosa*, and *Fraxinus excelsior*. Coordinates and other relevant information for each plot were recorded. Most of the *Fraxinus excelsior* and *Alnus glutinosa* stands were located within the Karacabey Forest Operations Directorate and Yeniköy Forest Operations Sub-directorate, while *Pinus brutia* and *Abies nordmanniana* stands were selected from areas with varying elevations and topographies to represent a range of ecological conditions.

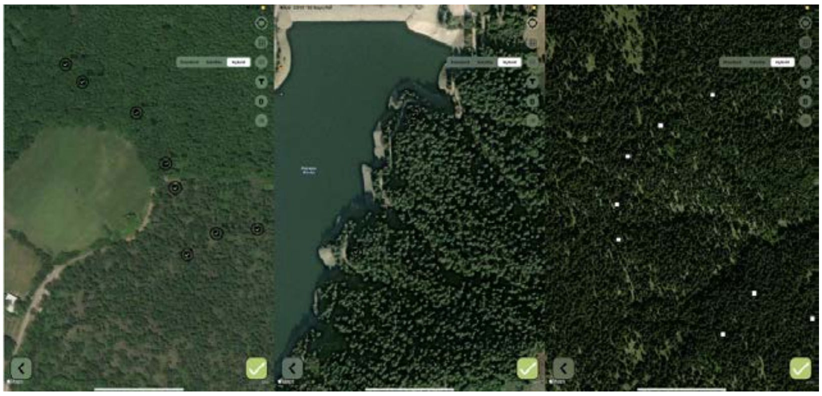


Figure 2. Sample areas

Different tree species were selected for this study due to their varying bark textures, crown structures, and canopy density. Measurements were conducted during midday to maximize sunlight exposure, ensuring optimal conditions for both manual and application-based measurements. The measurements were carried out using both direct and indirect methods. In direct measurements, traditional forestry instruments such as a Silva clinometer and/or Blume Leiss for height measurements, and a Haglöf caliper for diameter measurements, as illustrated in Figure 3, were used.


Figure 3. Instruments used for the measurements

## 2.3. Measurement Procedure

In each selected plot, measurements of DBH ($d_{1.30}$) and tree height (h) were taken for at least 30 sample trees per species (Figure 4.). All data were carefully recorded, and the calibration and accuracy of the measuring instruments were regularly checked throughout the fieldwork. For traditional measurements, both the time taken to perform each task, and the overall measurement process were recorded using a stopwatch.

Figure 4. Traditional DBH and tree height measurement

For measurements conducted using the Arboreal Forest application, DBH and height were measured and recorded in real-time, and summary reports were generated for each plot (Figure 5).

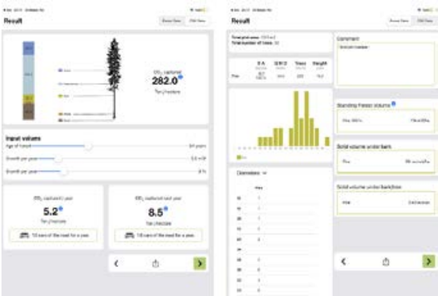



Figure 5. Summary reports of Arboreal application.

**2.4. Arboreal Application**

The Arboreal Forest and Arboreal Height applications, developed by the Arboreal company, were used for indirect measurements of DBH and tree height, respectively. These applications are widely available in app stores and provide a user-friendly interface for forest inventory tasks. The Arboreal Forest application enables users to create sample plots, number trees, and measure DBH, while the Arboreal Height application is used for height measurements (Figure 6).

In practice, the application guides users through the process of selecting a plot size, establishing a reference point, and measuring DBH by moving within the defined plot boundaries. Once DBH measurements are completed, the Arboreal Height application is used to measure the tree heights. The application utilizes augmented reality (AR) features to display all necessary information on the screen, including plot boundaries and tree numbers, and allows data export in *.csv* format for further analysis. Regardless of the measurement method, all data were compiled and processed using Microsoft Excel prior to analysis.

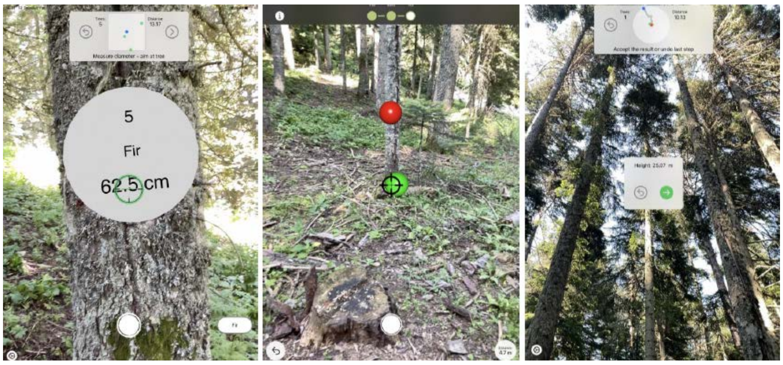



Figure 6. Arboreal application interface

### 2.5. Statistical Analysis

For the comparison of data obtained through traditional and Arboreal methods, the differences between the two sets of measurements were analyzed. Standard deviations of the differences were calculated for both DBH and height. Subsequently, the standard error (SE) of the errors, the root mean square error (RMSE), and the systematic bias were calculated using the following formulas:

$$RMSE = \sqrt{\frac{\sum(y_{arboreal} - y_{traditional})^2}{n}} \quad (1)$$

$$BIAS = \frac{\sum(y_{arboreal} - y_{traditional})}{n} \quad (2)$$

$$RMSE\,(\%) = \frac{RMSE}{\bar{y}} \times 100 \quad (3)$$

$$BIAS(\%) = \frac{BIAS}{\bar{y}} \times 100 \quad (4)$$

Where ($y_{arboreal}$, $y_{traditional}$) represents the difference between the measurements obtained via the Arboreal application and the traditional method, n is the number of trees measured, and $y$ represents the mean of the traditional measurements. After all measurements were completed, regression analysis was performed using SPSS software to determine whether there were significant differences between the traditional and application-based measurements.

### 3. Results and Discussion

Data collected from the field were digitized and transferred to the computer for processing. After cleaning and organizing the data, errors and missing entries were corrected. The dataset was then analyzed using SPSS and RStudio. The study focused on four tree species: *Pinus brutia*, *Abies nordmanniana subsp. bornmuelleriana*, *Alnus glutinosa*, and *Fraxinus excelsior*.

Measurements of DBH and tree height were conducted using both traditional tools (calipers, Blume Leiss, and clinometers) and the Arboreal application for comparison. The study included five sample plots for each species, with a total of 20 plots distributed across various locations. Plot sizes ranged from 400 to 800 square meters depending on canopy closure, and areas were expanded if fewer than 30 trees were present. In total, 600 trees were measured, and descriptive statistics are summarized in Table 1 and Table 2.

Table 1. Descriptive statistics of trees measured by traditional and arboreal method

| Species | Traditional Method | | | | | | Arboreal | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DBH (cm) | | | Tree height (m) | | | DBH (cm) | | | Tree height (m) | | |
| | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| *Fraxinus excelsior* | 21,0 | 35 | 9,7 | 11,9 | 21,2 | 6,4 | 20,3 | 38,4 | 7,0 | 12,4 | 21,5 | 5,9 |
| *Alnus glutinosa* | 36,1 | 54,6 | 20,4 | 20,9 | 25,5 | 8,3 | 35,5 | 56,2 | 20,8 | 20,8 | 25,4 | 9,2 |
| *Pinus brutia* | 29,6 | 65,9 | 8,3 | 16,3 | 31,4 | 6,2 | 29,5 | 61,9 | 9,2 | 15 | 29,7 | 4,5 |
| *Abies nordmanniana* | 32,1 | 60,5 | 10 | 17,9 | 34,2 | 5,7 | 32 | 55,6 | 9,1 | 15,7 | 24,9 | 6,6 |

Table 2. Descriptive statistics of time analysis by traditional and arboreal method

| Species | Traditional Method | | | | | | Arboreal | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DBH time (s) | | | Tree heigh time (s) | | | DBH time (s) | | | Tree heigh time (s) | | |
| | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| *Fraxinus excelsior* | 5,6 | 9,5 | 0,4 | 18,3 | 29,5 | 10,2 | 1,8 | 7,7 | 0,3 | 13,0 | 22,6 | 4,49 |
| *Alnus glutinosa* | 4,3 | 6,9 | 3,1 | 13,6 | 20,9 | 5 | 1,7 | 5 | 0,4 | 9,6 | 18,2 | 3,3 |
| *Pinus brutia* | 5,0 | 15,5 | 1,4 | 40 | 60 | 15 | 2,8 | 6,8 | 0,3 | 19,9 | 30 | 10 |
| *Abies nordmanniana* | 4,9 | 9,6 | 1,0 | 40,4 | 59,5 | 20,2 | 3,3 | 6,9 | 0,2 | 20,7 | 29,9 | 10,2 |

Both direct and indirect measurements were performed, with manual tools used for traditional measurements and the Arboreal application for digital measurements. Data from all methods were processed and analyzed to compare accuracy, standard deviations, and measurement time differences between the two methods.

The descriptive statistics for the trees measured using the traditional method and the Arboreal application reveal slight variations in DBH and tree height across the four species (Table 1). For *Fraxinus excelsior*, the mean DBH was 21.0 cm with the traditional method and 20.3 cm with the Arboreal app, while the mean tree height was slightly higher with the app (12.4 m) compared to the traditional method (11.9 m). For *Alnus glutinosa*, both methods produced similar results for tree height, with a mean of around 20.9 m, though DBH measurements were slightly lower using the app (35.5 cm vs. 36.1 cm). *Pinus brutia* measurements were consistent in DBH between methods (around 29.5 cm), but the mean height was lower with the app (15 m) compared to the traditional method (16.3 m). For *Abies nordmanniana*, the average DBH was almost identical between methods (32.1 cm vs. 32.0 cm), but tree height measurements were notably lower with the app (15.7 m vs. 17.9 m).

The histograms display the distribution of DBH and tree height measurements for four species (*Fraxinus excelsior*, *Alnus glutinosa*, *Pinus brutia*, and *Abies nordmanniana*) using both traditional and Arboreal methods. In general, the two methods show similar distribution patterns, though the Arboreal method tends to estimate slightly lower values in some cases, particularly for DBH and lower height ranges. The differences between the methods are more pronounced in species like *Pinus brutia* and *Abies nordmanniana*, where the Arboreal app appears to capture broader distributions (Figure 7).

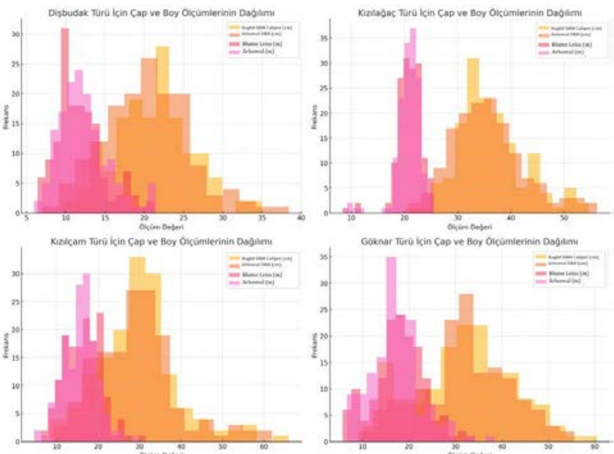



Figure 7. Comparison of DBH and tree height measurements between traditional and arboreal methods for different tree species

Time analysis for DBH and tree height measurements reveals notable differences between the traditional method and the Arboreal application (Table 2). For *Fraxinus excelsior*, DBH measurements took an average of 5.6 seconds using traditional methods, while the Arboreal app significantly reduced this time to an average of 1.8 seconds. Similarly, tree height measurements using traditional methods averaged 18.3 seconds, compared to 13.0 seconds with the Arboreal app. For *Alnus glutinosa*, the traditional method required an average of 4.3 seconds for DBH and 13.6 seconds for height measurements, while the Arboreal app reduced these times to 1.7 and 9.6 seconds, respectively. For *Pinus brutia*, the traditional method averaged 5.0 seconds for DBH and a substantial 40 seconds for tree height, whereas the Arboreal app reduced the time to 2.8 seconds for DBH and 19.9 seconds for height. Lastly, for *Abies nordmanniana*, DBH measurement times were reduced from an average of 4.9 seconds using traditional methods to 3.3 seconds with the app, and tree height measurements dropped from 40.4 seconds to 20.7 seconds.

The histograms represent the measurement time distributions for DBH and tree height using both traditional tools (Haglöf caliper and Blume Leiss) and the Arboreal application across four species (*Fraxinus excelsior*, *Alnus glutinosa*, *Pinus brutia*, and *Abies nordmanniana*). The graphs show that the Arboreal application consistently reduced the time required for both DBH and height measurements compared to traditional methods, especially for species like *Fraxinus excelsior* and *Kızılçam*. The time savings are most evident in DBH measurements, where the Arboreal method exhibits shorter measurement times. These results emphasize the efficiency of the Arboreal application, particularly in reducing time for large-scale forest inventories (Figure 8).

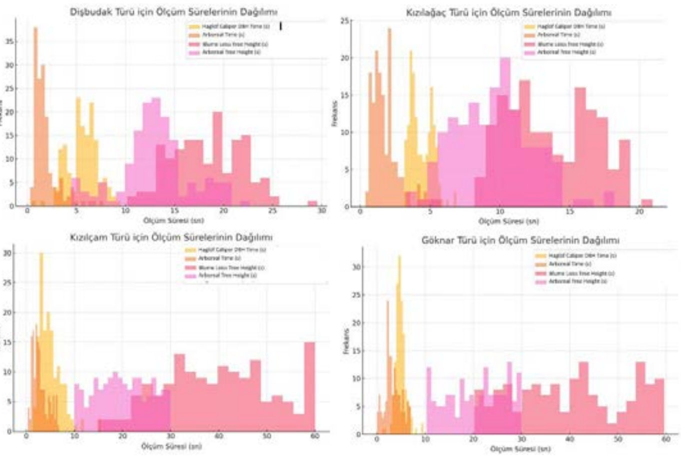



Figure 8. Comparison of DBH and tree height measurements time between traditional and arboreal methods for different tree species

The correlation analysis was conducted to assess the relationship between measurements obtained through traditional methods and the Arboreal application, following the descriptive analysis. This step helps to determine the consistency between the two methods, ensuring that time-efficient digital tools provide measurements comparable to established techniques.

The correlation matrix provides valuable insights into the relationship between the measurement methods and the associated times. Strong positive correlations between diameter and height measurements across traditional and Arboreal methods indicate that both techniques yield similar results, confirming the reliability of the Arboreal app. The high correlation values, particularly between the diameter and height measurements (e.g., 0.97 for

DBH), show that the Arboreal method performs comparably to traditional tools like calipers and clinometers.

On the other hand, the relatively low correlations observed between the measurement times (e.g., 0.31 between DBH measurement times) suggest that the time savings offered by the Arboreal app do not come at the cost of accuracy. These findings demonstrate that, while the Arboreal app significantly reduces the time required for data collection, it still maintains precision, making it a practical and efficient tool for fieldwork in forestry. (Figure 9).

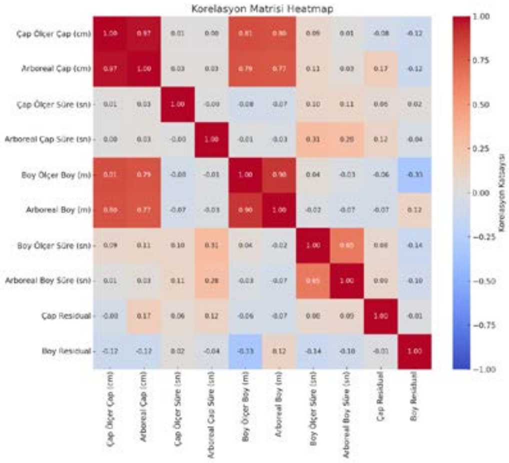



Figure 9. Correlation matrix of diameter, height, and measurement times for traditional and arboreal methods

In this study, the accuracy and bias of the measurements obtained using the Arboreal application were compared to those obtained through traditional methods for DBH and tree height. The values for standard error (SE), root mean square error (RMSE), and bias across all species are presented in Table 3.

Table 3. SE, RMSE, Bias for DBH and tree height measurements

| Measurements | SE | RMSE | Bias | RMSE% | Bias% |
|---|---|---|---|---|---|
| DBH | 0.098 | 2.449 | 0.380 | 8.244 | 1.281 |
| Tree Height | 0.094 | 2.328 | 0.262 | 13.890 | 1.566 |

For DBH measurements, the RMSE value is relatively low across all species (2.449 cm), with a small bias of 0.380 cm. The percentage RMSE of 8.24% indicates that the Arboreal method provides highly accurate DBH measurements. Tree height measurements showed a higher RMSE of 2.328 m, with a bias of 0.262 m, indicating slightly more variability in height measurements. However, the bias remains within acceptable limits, with only 1.57% bias for tree height measurements. Following the accuracy analysis, the efficiency of the Arboreal application in terms of time savings was evaluated. The SE, RMSE, and bias for measurement times are provided in Table 4.

Table 4. SE, RMSE, Bias for DBH and tree height measurement times

| Measurements | SE | RMSE | Bias | RMSE% | Bias% |
|---|---|---|---|---|---|
| DBH | 0.091 | 3.398 | 2.553 | 68.295 | 51.309 |
| Tree Height | 0.479 | 16.957 | 12.252 | 60.404 | 43.644 |

The time efficiency of the Arboreal application is significant, with RMSE values of 3.398 seconds for DBH measurements and 16.957 seconds for tree height measurements. These values indicate that the Arboreal method substantially reduces the time needed for measurement, especially for DBH, where the bias percentage reaches 51.3%. The reduction in time for tree height measurements is also noteworthy, with a 60.4% RMSE in time.

A paired sample t-test was conducted to evaluate the statistical significance of differences between measurements obtained using the Arboreal application and traditional methods. The T-statistics and P-values are presented in Table 5.

Table 5. Paired Sample T-Test for DBH and Tree height measurements

| Measurements | t | p |
|---|---|---|
| DBH | 3.851 | 0.061 |
| Tree Height | 2.777 | 0.055 |
| DBH Time | 27.861 | 0.000 |
| Tree Height Time | 25.578 | 0.000 |

The results of the t-test show that there is no statistically significant difference between DBH and tree height measurements obtained through the Arboreal app and traditional methods (P-values of 0.061 and 0.055, respectively). However, the time differences for both DBH and tree height are highly significant ($P < 0.001$), confirming that the Arboreal app offers substantial time savings while maintaining measurement accuracy.

To further explore the results, species-specific differences in DBH, tree height, and measurement times were analyzed. While there were no significant differences in DBH measurements for any species, *Fraxinus excelsior* showed a borderline significant difference in tree height measurements ($P = 0.050$), and *Pinus brutia* exhibited some variability in tree height ($P = 0.055$). Time savings were consistent across all species, with significant reductions in measurement times for both DBH and tree height.

## 4. Conclusion and Suggestions

The results of this study confirm that the Arboreal application provides both accurate and time-efficient measurements for tree diameter and height, demonstrating strong correlations with traditional methods. The low RMSE and bias values indicate that the Arboreal app is a reliable alternative to conventional tools, offering comparable measurement accuracy. The significant time savings, particularly in height and DBH measurements, make it an asset for large-scale forestry operations, allowing for quicker data collection without compromising precision. These factors position the Arboreal app as an effective tool for enhancing forest inventory and management practices.

While the Arboreal app has demonstrated its utility, further research should explore its performance under different environmental conditions, tree species, and user experiences to ensure its versatility. Additionally, since the Arboreal application operates as a paid tool, it is important for future studies to assess the cost-benefit ratio, particularly for small-scale or community-based forestry operations, where budget constraints may be an issue. Testing the app across a range of devices, such as smartphones and tablets with varying hardware capabilities, would help determine its adaptability and consistency. Furthermore, integrating advanced features like LiDAR technology, cloud-based data synchronization, or augmented reality could further enhance its functionality, making it even more attractive for modern forestry management.

**Acknowledgements**
This study was supported by the TÜBİTAK 2209-A Research Project Support Program. We would like to express our sincere gratitude to The Scientific and Technological Research Council of Türkiye (TÜBİTAK) for their financial support, which made this research possible.
We are deeply thankful to Dr. Johan Ekenstedt, CEO of Arboreal, for generously providing us with free access to the Arboreal Forest and Height applications.

**References**
Arboreal, 2019. Arboreal skog. Available at: https://www.arboreal.se/en/arboreal-forest/
Assessment, G.F.R. 2010. Main report. Food and Agriculture Organization of the United Nations, Rome.
Bijak, S. and Sarzyński, J. 2015. Accuracy of smartphone applications in the field measurements of tree height. Folia Forestalia Polonica, 57(4), pp.240-244.
Fan, Y., Feng, Z., Mannan, A., Khan, T.U., Shen, C., Saeed, S. 2018. Estimating tree position, diameter at breast height, and tree height in real-time using a mobile phone with RGB-D SLAM. Remote Sensing, 10(11):1845.
Ficko, A. 2020. Bayesian evaluation of smartphone applications for forest inventories in small forest holdings. Forests, 11(11):1148.
Gülci, S., Yurtseven, H., Akay, A.O., Akgul, M. 2023. Measuring tree diameter using a LiDAR-equipped smartphone: a comparison of smartphone-and caliper-based DBH. Environmental Monitoring and Assessment, 195(6):678.
Köhl, M., Magnussen, S., Marchetti, M. 2006. Sampling methods, remote sensing and GIS multiresource forest inventory (Vol. 2). Berlin: Springer.
Loetsch, F., Zohrer, F., Haller, K.E. 1973. Forest inventory. Volume II. Inventory data collected by terrestrial measurements and observations. Data processing in forest inventory. The sample plot. Plotless sampling and regeneration survey. List sampling with unequal probabilities. Planning, performance and field checking of forest inventories.
Tatsumi, S., Yamaguchi, K., Furuya, N. 2023. ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad. Methods in Ecology and Evolution, 14(7):1603-1609.
Tomaštík, J., Saloň, Š., Tunák, D., Chudý, F., Kardoš, M. 2017. Tango in forests–An initial experience of the use of the new Google technology in connection with forest inventory tasks. Computers and Electronics in Agriculture, 141:109-117.
Ucar, Z., Değermenci, A.S., Zengin, H., Bettinger, P. 2022. Evaluating the accuracy of remote dendrometers in tree diameter measurements at breast height. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering, 43(1):185-197.
Van Laar, A., Akça, A. 2007. Forest mensuration (Vol. 13). Springer Science & Business Media.
Villasante, A. and Fernandez, C. 2014. Measurement errors in the use of smartphones as low-cost forestry hypsometers. Silva Fennica, 48(5).
Wu, X., Zhou, S., Xu, A., Chen, B. 2019. Passive measurement method of tree diameter at breast height using a smartphone. Computers and Electronics in Agriculture, 163, p.104875.

# Assessment of PM10 Exposure in Chainsaw Operators During Tree Felling

**İnanç Taş**

Bursa Technical University, Faculty of Forestry, Bursa, Türkiye
inanc.tas@btu.edu.tr

## Abstract

One of the most important stages of forestry production is the felling of trees. The use of advanced production machines is difficult in places with rugged terrain such as Türkiye. Therefore, chainsaws are generally preferred for these operations. Although chainsaws seem to be easy to use, they have various negative effects. It is an important issue that especially cutting operators are affected by particulate matter (PM10) formed during cutting. This study was carried out in Bursa, Soğukpınar Forest Management Directorate. In the study, 45 trees were felled. Especially PM10 from the use of chainsaws has a significant impact on cutting operators. PM10 was measured from the breathing zone of the chainsaw operator during tree felling. The average PM10 value measured was 361.8 µg/m$^3$ PM10 per minute. In total, 16280 µg/m$^3$ PM10 was measured. These values may seem quite small, but operators are affected by the total amount of PM10 during long hours of work. According to the United States Environmental Protection Agency (EPA), air quality is unhealthy when the daily exposure index value is over 150 µg/m$^3$. Therefore, the values measured during the study are quite high. According to the EPA's air quality index, 361.8 µg/m$^3$ is in the "Very Unhealthy" group.

***Keywords:*** *Chainsaw, occupational health, particulate matter, tree felling*

## 1. Introduction

Forestry is an important sector that encompasses a wide range of working methods, from the simplest techniques to advanced technologies. In the early days, production was carried out using human labor, but over time, technology-based production methods have been adopted in this sector. The complexity of current working methods has made it nearly inevitable for accidents or risky situations caused by human or machine resources to arise during forestry activities. For example, continuing human labor while production is carried out by machines can lead to work accidents, injuries, occupational diseases, and labor losses (Kaakkurivaara et al., 2022). Additionally, experts and operators working with machines are also affected by machine-related risks. Today, many forestry production activities involve the use of chainsaws, which can be considered the simplest machine used in production. However, alongside the conveniences they offer, there are also associated risks. Among these risks, the formation of particulate matter holds significant importance.

Particulate matter is described as solid particles that can remain suspended in the air and tend to settle over time due to their weight. Larger particulate matter with higher density can settle quickly, while particles with lower density can remain airborne for extended periods. Particulate matter with sizes ranging from 0.5 to 10 microns can enter the body through the respiratory tract. The negative effects of particles on human health are related to their size. Generally, particles smaller than 2.5 microns (PM2.5) and 10 microns (PM10) are considered significant (Taş and Akay, 2019). These are referred to as fine and coarse particles, respectively. Particulate matter larger than 10 microns is trapped in the upper respiratory tract, while smaller particles such as PM10 and PM2.5 can reach the alveoli. Therefore, particulate matter smaller than 10 microns poses the greatest health risk. Particles smaller than 10 microns accumulate in the bronchi, while those with a diameter of 1-2 microns settle in the alveoli, and particles with a diameter of 0.1 microns can pass from the alveoli into capillaries. Particulate matter can cause a range of health issues, including decreased lung function, asthma attacks, irritation of the respiratory tract, shortness of breath, early death in individuals with heart or lung diseases, and heart attacks (Contini and Costabile, 2024). In addition to causing workplace accidents and occupational diseases, particulate matter also reduces work efficiency, damages machinery and products, and complicates working conditions.

Particulate matter has numerous effects on health. During forestry production activities, particulate matter formation is often encountered. This study investigates the particulate matter generated by chainsaw operations and examines its potential effects on the operator.

## 2. Material and Methods

### 2.1. Study Area

This study was carried out in Bursa Sogukpinar Forest Management Directorate (Figure 1). There are beech (Fagus orientalis) and black pine (Pinus nigra) trees in the study area. Measurements were made during the felling of black pine trees. Only Particulate Matter 10 (PM10) was considered in the measurements. Wind speed in the environment varies between 0-3 meters per second.

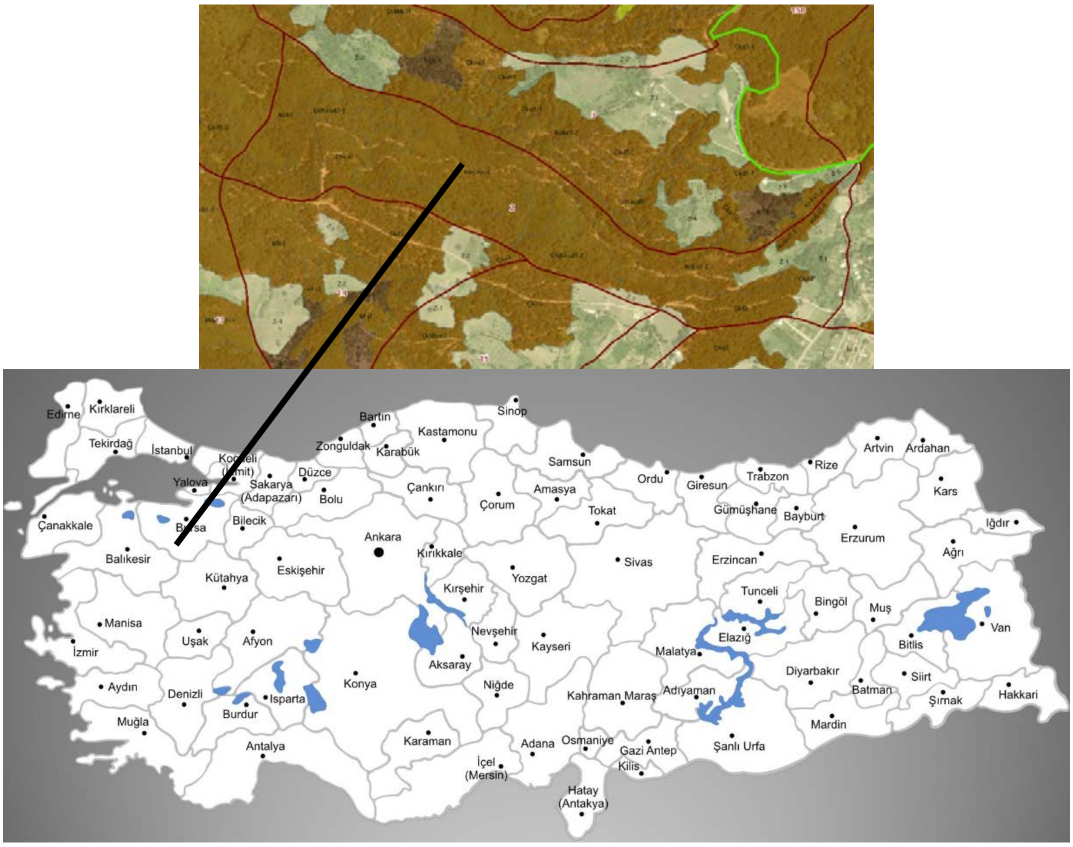


Figure 1. Study area in Soğukpınar Forest Management Directorate in Bursa

### 2.2. Equipment Used in the Study

PCE-MPC 10 model particle measurement device (Figure 2) was used in this study. Some technical specifications of the device are given in Table 1.

Table 1. PCE-MPC 10 model particle measurement device specifications

| Particle specifications | |
|---|---|
| Particulate matter channels | PM 2.5 / PM 10 |
| Particle sizes (in micrometers) | 2.5 µm, 10 µm |
| Particle concentrations | 0 ... 2000 µg / m³ |
| Resolution | 1 µg / m³ |

Figure 2. PCE-MPC 10 model particle measurement device

Particulate matter (PM10) was measured from the breathing zone of the chainsaw operator during felling (Figure 3). In this type of studies, measurements are made from the breathing zone (Leszczynski, 2014). A total of 45 trees were felled in this study. All trees were measured. From the total cutting time of each tree, 1-minute sections were measured. This is because the device only works in 30 seconds, 1 minute and 2 minutes measurement periods. Therefore, the total measurement time is 45 minutes. In addition, 2 minutes measurements were not preferred in order to ensure sufficient battery time.

Figure 3. PM10 measurement in operator's breathing zone

## 3. Results

Considering the collected data, an average of 361.8 µg/m³ PM10 was measured per minute. In total, 16280 µg/m³ PM10 was measured. These values may seem quite small, but operators are affected by the total amount of PM10 during long hours of work. According to the United States Environmental Protection Agency (EPA) (2024), the environment is unhealthy when the 24-hour exposure index value exceeds 150 µg/m³ (Table 2). Therefore, the values found are quite high.

If the table had been analyzed by taking the 1-minute average value into consideration, the value of 361.8 µg/m³ would have been in the 'Very Unhealthy' group according to EPA's air quality index. However, according to EPA, the total exposure value of 24 hours should be taken into consideration. The total PM10 value obtained in the 45-minute measurements made in this study was found to be 16280 µg/m³. Even if the rest of the day is not taken into consideration, these values are quite high.

Table 2. United States Environmental Protection Agency, Air Quality Index

| PM10 (µg/m³) | AQI Value | Air Quality | Description |
|---|---|---|---|
| 0-54 | 0-50 | Good | Air quality is considered satisfactory; air pollution poses little or no risk. |
| 55-154 | 51-100 | Moderate | Air quality is acceptable; however, for some pollutants, there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution. |
| 155-254 | 101-150 | Unhealthy for Sensitive Groups | Members of sensitive groups may experience health effects. The general public is not likely to be affected. |
| 255-354 | 151-200 | Unhealthy | Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects. |
| 355-424 | 201-300 | Very Unhealthy | Health alert: everyone may experience more serious health effects. |
| 425 and above | 301 and above | Hazardous | Health warnings of emergency conditions. The entire population is more likely to be affected. |

## 4. Conclusion

Particulate matter causes a significant risk for forest production workers. This situation is more effective especially in windless weather. Operators exposed to particulate matter should use EN 149 type masks that significantly filter dust and particulate matter and provide clean breathing (Rasekh et al., 2024). Operational measures to be taken against particulate matter can be taken such as operators working in shifts, organizing working hours and increasing the need for breaks.

To reduce PM10 levels in forestry production activities, several measures can be taken. In logging and chipping operations, it is essential to use electric chainsaws with low dust emissions, conduct cutting processes in humid weather conditions, and employ effective cutting techniques. During chipping, using modern machines equipped with emission-reducing filter systems and applying water to minimize dust dispersal is also important. Furthermore, in forest management, planning operations in advance can prevent unnecessary logging, while natural methods can be utilized to combat diseases and pests effectively. In terms of community awareness, educating forestry workers about the effects of PM10 and methods for emission reduction is crucial, along with promoting the adoption of environmentally friendly practices. Lastly, establishing monitoring stations in forested areas will allow for continuous tracking of air quality and PM10 levels. These measures contribute to reducing PM10 emissions in forestry production processes (Cooper and MacFarlane, 2023; Huang, 2023).

**References**

Contini, D., Costabile, F. 2024. Air Pollution, Health Effects Indicators, the Exposome, and One Health. Atmosphere, 15(5):618.

Cooper, L., MacFarlane, D. 2023. Climate-Smart Forestry: Promise and risks for forests, society, and climate. PLOS Climate, 2(6): e0000212.

Environmental Protection Agency. 2024. National Ambient Air Quality Standards (NAAQS) table. Retrieved July 19, 2024, from https://www.epa.gov/criteria-air-pollutants/naaqs-table

Huang, X. 2023. The Impact of PM10 and Other Airborne Particulate Matter on the Cardiopulmonary and Respiratory Systems of Sports Personnel under Atmospheric Exposure. Atmosphere, 14(11): 1697.

Kaakkurivaara, T., Borz, S. A., Kaakkurivaara, N. 2022. Risk factors and occupational safety failures in forest work in the Southeast Asian region. Forests, 13(12):2034.

Leszczynski, K. 2014. The concentration of carbon monoxide in the breathing areas of workers during logging operations at the motor-manual level. International Journal of Occupational Medicine and Environmental Health, 27 (5): 821-829.

Rasekh, M., Pisapia, F., Hafizi, S., Rees, D. 2024. Filtering Efficiency and Design Properties of Medical-and Non-Medical-Grade Face Masks: A Multiscale Modeling Approach. Applied Sciences, 14(11): 4796.

Taş, İ., Akay, A.E. 2019. Analysis of Dust Exposure during Chainsaw Felling Operations. V. Science Technology and Innovation Congress. Alanya, Antalya, Turkey: April 17-21.

# Calculation of Log Stack Volume Using Spatial Photos

**İnanç Taş*, Burhan Gencal, Emre Kılınçarslan**

Bursa Technical University, Faculty of Forestry, Bursa, Türkiye
*inanc.tas@btu.edu.tr

## Abstract

The logs are stored in depots at the end of the wood production stages in forestry. The logs are stacked in the depot and the diameter, length and volume are noted. Basic tools such as calipers and meters are generally used in these measurements. Nowadays, these operations can be made with phones because of spatial photos. The volume of an object can be calculated by scanning it with photos. These photos are converted into 3D models with some programs. One of these programs is Agisoft Metashape. Many operations can be performed by processing photos with Metashape. In this study, it is aimed to produce a 3D model with Metashape and to calculate the volume information of the model and to compare it with the manual method. In this study, photos were taken around a log stack at Bayramdere Forest Depot in Bursa. These photos were processed in Metashape program. At the last stage, a 3D model was produced, and its volume was calculated. The same log stack were measured manually and volume was calculated. According to the results, the volume calculated by the manual method was 3.468 $m^3$ and the volume calculated by Metashape was 3.694 $m^3$.

***Keywords:*** *3D model, Agisoft Metashape, log stack, volume calculation*

## 1. Introduction

In forestry production, the logs obtained are stored in depots. The diameter, length, and volume information of the products brought to the depots are measured separately for each log stack. These measurements are made using calipers and tape measures. Such traditional methods are easy to implement. While diameter and length measurements are generally accurate, volume calculations can be erroneous due to the shape of the logs. With advancing technology, the use of photos or LiDAR data for volume measurements has started to become more common. Programs like Agisoft Metashape and similar software can be utilized in studies requiring such volume measurements due to their ability to process images or point clouds.

Recent developments in three-dimensional (3D) information technologies and digital data acquisition have attracted the interest of researchers (Shao et al., 2016; Manzoor et al., 2021). Ongoing efforts aim to minimize human errors in capturing 3D data. 3D reconstruction enables the retrieval of an object's geometry and appearance (Mahami et al., 2019). Photogrammetry and laser scanning are effective techniques for extracting detailed 3D scenes and point clouds, though laser scanning has limitations, such as challenges in indoor environments and high processing requirements (Bianco et al., 2018). In contrast, photogrammetry uses overlapping images from visual sensors, providing cost efficiency and automation capabilities (Kortaberria et al., 2018). One of the important programs used in this field is Agisoft Metashape.

Agisoft Metashape program is an independent software product that enables the scanning of physical objects and the transfer of their data into a computer environment, producing three-dimensional spatial data for indirect measurements of objects at various scales (BC Digital Scholarship, n.d.). With Agisoft, which has the feature of automatically calibrating cameras, it is possible to create a three-dimensional (3D) model from photos taken with cameras and to produce photogrammetric base maps. This and similar software implement the Structure from Motion (SfM) approach in the photogrammetric evaluation process (Apollonio et al., 2021). In this approach, a 3D model is created using matched points from all the photos, whether they are coordinated or uncoordinated.

In the study, a 3D model of a log stack in the forest depot was created using photos. Subsequently, the volume of the model was calculated. In the next phase, volume results obtained from traditional measurements (calipers and tape measures) were gathered. In the final stage, the values obtained from the two different methods were compared.

## 2. Material and Methods

### 2.1. Study Area

In the study, Bayramdere Forest Depot located in Bursa was selected for measuring log stacks (Figure 1). There are many logs stored in stacks at the depot. One of these stacks was selected for measurements. Diameter and length information were recorded, and a series of photos containing location information were taken.

Figure 1. Study area

A Xiaomi Mi 9T model phone, a caliper, and a tape measure were used for the measurements. First, the diameter values at the ends of the logs and the length values were measured using the caliper and tape measure. Since the logs were stacked, diameter values for the sections were not taken. For more accurate measurements, it would be appropriate to take diameter values from the 0, 1, 2, and 3-meter marks, i.e., from one-meter sections. However, since the logs in the stack could not be moved, the diameter measurements were taken from the ends. Under normal conditions, these operations are conducted by depot workers who take only the middle diameter before creating the stacks. Subsequently, photos containing location information were taken with the Xiaomi Mi 9T model phone. The photos were taken to scan the entire stack, totaling 134 images (Figure 2).

Figure 2. Examples of the series of photos taken

**2.2. Calculation of Volumes Using Traditional Methods**

The data collected in the depot were later used in the office environment to calculate the volume information. Utilizing the diameter and length measurements of the logs, the volume of each log was calculated, and then the total volume was determined (Table 1).

Table 1. Log diameter-length information and calculated total volume information

| Logs No | First Diameter (cm) | Second Diameter (cm) | Length (m) | Volume (m3) |
|---|---|---|---|---|
| 1 | 40.5 | 42.5 | 3 | 0.406 |
| 2 | 20.5 | 24.8 | 3 | 0.121 |
| 3 | 40.5 | 39 | 3 | 0.372 |
| 4 | 30 | 40 | 3 | 0.288 |
| 5 | 46 | 37.8 | 3 | 0.413 |
| 6 | 45.5 | 78.5 | 3 | 0.905 |
| 7 | 40.5 | 38 | 3 | 0.363 |
| 8 | 55 | 46 | 3 | 0.601 |
| | | | Total Volume | 3.468 |

**2.3. 3D Model Production and Volume Calculation with Metashape**

A total of 134 photos obtained from the log stack were used to produce a 3D model (Figure 3), followed by volume calculation based on the created model. At this stage, the photos were first added to the Metashape program, where connection points were established through the Tie Point operation, resulting in a total of 23,354 points generated. In the next step, the Dense Cloud process was performed to obtain the point cloud, generating approximately 16 million points. All operations were conducted at high resolution.

Figure 3. 3D log stack model

A digital elevation model (DEM) was created using the dense point cloud. A polygon was then generated by selecting the ground points from the produced DEM. Above this reference polygon, a log stack was identified. By utilizing the measurement tool on the ground polygon, the total volume of the logs positioned above it was calculated. The volume of the logs above the ground was determined to be 3.694 m³ (Figure 4). A significant part of the volume remaining at the bottom of the polygon can be attributed to the unevenness of the soil surface. As a result, this value was disregarded in the analysis.

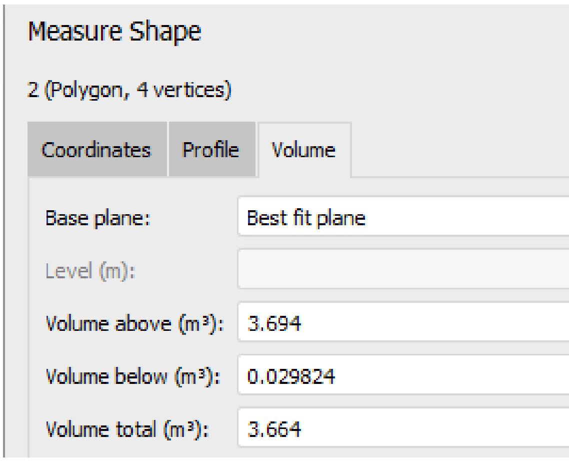



Figure 4. Volume values in Metashape

**3. Results**

When comparing the volume values obtained in the study, the traditional method yielded a volume of 3.468 m³, while Metashape provided a volume of 3.694 m³. This comparison reveals a volume difference of approximately 9% to 10%. This discrepancy may arise from the gaps between the logs. Additionally, since blind spots in the images cannot be accurately calculated with Metashape, the values for the parts of the model created through interpolation may differ from the actual values. In Figure 5, the red areas indicate regions that could not be clearly scanned in the photos. However, it appears that the log stack was scanned significantly well. In Figure 6, a specific area of the model is selected and presented along with a close-up image of that area, allowing for a view of the model's triangular structure.

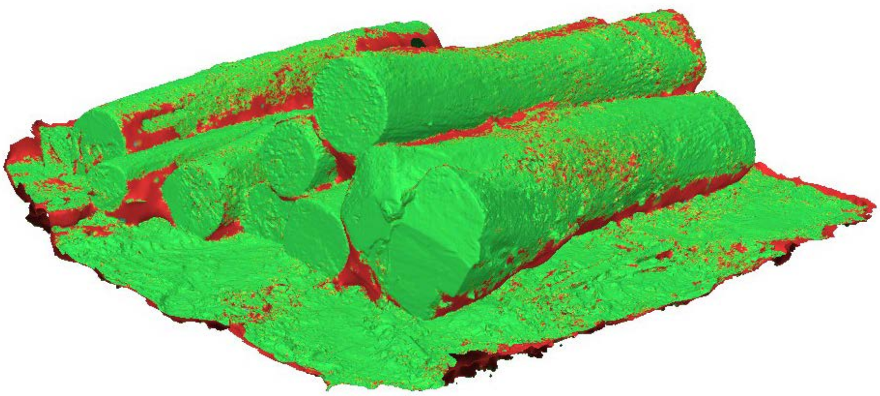


Figure 5. Areas that could not be clearly scanned in the photos (red areas)

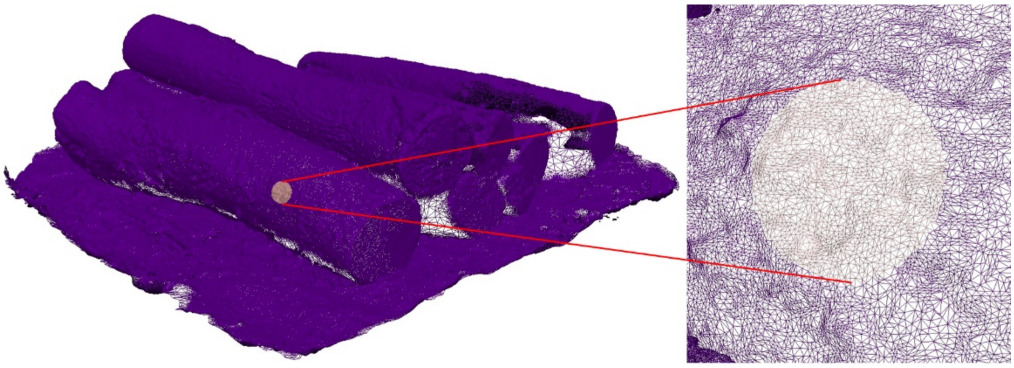


Figure 6. Close-up view of the triangular model and a section of the model

## 4. Conclusion

With advancing technology, traditional manual measurement methods have started to be replaced by new computer-aided systems. In this study, a sample log stack was scanned using photos to obtain volume values, which were then compared with values obtained through traditional methods. According to the results, if the volume values obtained by traditional methods are considered accurate, a measurement value approximately 9% to 10% higher was achieved with the new method. This discrepancy is thought to arise from blind spots and gaps that could not be captured during the measurements. Considering that these values are likely to produce similar results in other stacks, it is suggested that using devices capable of scanning larger areas, such as drones, could be an effective method for simultaneously scanning many more stacks to estimate their volume values. Additionally, this method may also be useful for calculating the volume of standing trees or specific forest areas. This way, values close to reality can be estimated quickly without the need for ground measurements.

## References

Apollonio, F. I., Fantini, F., Garagnani, S., Gaiani, M. 2021. A photogrammetry-based workflow for the accurate 3D construction and visualization of museums assets. Remote Sensing, 13(3): 486.

BC Digital Scholarship. (n.d.). Intro to photo processing with Agisoft Metashape for 3D model making. Retrieved October 25, 2024, from https://bcds.gitbook.io/learn/photogrammetry/agisoft-metashape

Bianco, S., Ciocca, G., Marelli, D. 2018. Evaluating the performance of structure from motion pipelines. Journal of Imaging, 4(8): 98.

Kortaberria, G., Mutilba, U., Gomez-Acedo, E., Tellaeche, A., Minguez, R. 2018. Accuracy evaluation of dense matching techniques for casting part dimensional verification. Sensors, 18(9):3074.

Mahami, H., Nasirzadeh, F., Hosseininaveh Ahmadabadian, A., Nahavandi, S. 2019. Automated progress controlling and monitoring using daily site images and building information modelling. Buildings, 9(3): 70.

Manzoor, B., Othman, I., Pomares, J. C. 2021. Digital technologies in the architecture, engineering and construction (Aec) industry—a bibliometric—qualitative literature review of research activities. International journal of environmental research and public health, 18(11): 6135.

Shao, Z., Yang, N., Xiao, X., Zhang, L., Peng, Z. 2016. A multi-view dense point cloud generation algorithm based on low-altitude remote sensing images. Remote Sensing, 8(5): 381.

# Assessing Windthrow Impact in Kastamonu Forests: Environmental Factors and Sentinel-2A Imagery Analysis

**Abdurrahim Aydın*, Tunahan Çınar, Nihat İşlek**

Düzce University, Faculty of Forestry, Konuralp Campus, 81620 Düzce, Türkiye
*aaydin@duzce.edu.tr

**Abstract**

In recent years, the frequency of severe storms worldwide has surged due to climate change, causing significant damage to forests and increasing degradation. The most notable impact on forests is windthrow, where trees are uprooted or broken by strong winds. This study at the Kastamonu Forest Regional Directorate in Türkiye from 2017 to 2021 examined the relationship between windthrow sizes and environmental parameters. Using Sentinel-2A satellite imagery, the Normalized Difference Fraction Index (NDFI) was calculated to determine windthrow sizes. The relationships of windthrow sizes with environmental parameters were modeled using regression tree. The Akaike information criterion (AIC) identified the best model, which included site index, maximum wind speed and slope. According to the model results, the widest windthrow sizes were found to occur when the site index was "I" and the wind speed exceeded 63.93 km/h. The statistical results of the regression tree model in an $R^2$ of 0.81, MAE of 0.29 and RRMSE of 3.02. To prevent degradation caused by windthrow, area-based conservation efforts should be implemented and silvicultural interventions should consider environmental parameters.

***Keywords:*** *Windthrow, environmental parameters, remote sensing*

## 1. Introduction

There are approximately 4.06 billion hectares of forest area in the world, which corresponds to about one-third of the land area (MacDicken et al., 2016). Forest areas, one of the biggest ecosystems in the world, has been exposed to biotic and abiotic damages. The exposure of forest areas to biotic and abiotic damage affects their sustainability. Among the abiotic damages affected the sustainability of forests are wildfires, windthrow, snow, avalanches and droughts. Among the most widespread biotic factors caused damage to forests has been insects and fungi (Lundquist et al., 2015). Early detection of biotic damage affected forests enables preventive measures to be taken for other forest areas. However, it has not been very possible to took preventive measures against abiotic damages that harm forests. Because abiotic damages unexpectedly and suddenly cause severe damage to forests (Teshome et al., 2020; Alforo et al., 2021). In recent years, an increase in the frequency of wildfires, windthrow and drought has been observed due to the impact of global climate change and the unconscious behaviors of humans (Venäläinen et al., 2020; Dale and Beyeler, 2001). Each of the wildfires, windthrow and drought which cause damage to forests on a global scale, has separate consequences. However, in recent years there has been a significant increase in windthrow in many locations globally (Hanewinkel et al., 2011; Kautz et al., 2017).

Storms were air currents with a speed of at least 15 km per hour, and they cause damaged to forests depending on speed and whether they blow continuously or suddenly and periodically.

If the storm blows in suddenly, this can become dangerous by shaking trees. Therefore, severe storms has been less dangerous than storms that blow in light suddenly (Ingold, 2005; Kidston et al., 2015). As a result of storms and strong winds, the uprooting of standing trees from the soil was referred to as windthrow (Mayer, 1989; Canham et al., 2001). Storm damages in forest areas, characterized by the sudden, unplanned and undesired occurrence of thousands or even millions of cubic meters of windthrow damage, pose a disaster for forest management. Storm damage affecting forest resources lead to significant losses in many regions (Dhubháin and Farrelly, 2018; Maurer and Heinimann, 2020).

Windthrow varies according to many environmental factors. The impact of environmental factors on windthrow impact has been researched in researchs, considering parameters such as elevation, slope, tree root type, forest stand type (pure and mixed), site index, soil texture, distance to road , wind speed and precipitation. Each parameter plays a role in the formation of windthrow and was preferred to be used in the modeling stage (Smiley et al., 2000; Sinton et al., 2000; Skłodowski, 2020). Elevation, which affects windthrow, was often associated with rainfall and forest health (Sagredo et al., 2014). On slopes, if the wind creates a corridor to reach steep slopes, it could cause damage, but typically degradation occurs in flat areas. On the other hand, the root type stabilizes the trees in windthrow areas (Krišāns et al., 2020), while the mixture condition of forests could reduce the impact of degradation by creating a windbreak (Griess and Knoke, 2011). As the site index, known as the productivity power, increases the height and diameter of trees could expanded. However, they become more susceptible to windthrow because storms affect a larger area of trees, increasing the damage (Cucchi et al., 2005). The soil texture structure reduces the impact of windthrow by stabilizing tree roots in the soil (Taylor et al., 2019). Forest roads, as another environmental parameter make easier the entry of wind into the forest and lead to degradation (Kunert et al., 2015). Precipation, one of the climate parameters affecting windthrow, softens the soil and makes tree falls easier (Scott and Mitchell, 2005), while the size of the degradation area could vary depending on wind speed (Anyomi et al., 2017).

Many parameters are important in the formation of windthrow and the variation in the size of affected areas and it was necessary to identify these parameters in windthrow areas. The detection of environmental parameters and the assessment of resulting degradation have been carried out with the help of ground measurements or remote sensing data (Kerr and Ostrovsky, 2003). While the cost may increase in in-situ detection of each windthrow area, using satellite imagery to identify the areas and determine the necessary measures has been preferred. This preference is due to the need to take necessary measures before insect species that could harm forests in areas affected by storm damage arrive in degradation areas. Forested areas degraded by windthrow need to be identified quickly to prevent further damage (Schelhaas et al., 2003; Seidl and Rammer, 2017). Optical and radar remote sensing data are used to quickly locate the windthrow. Remote sensing data that enables the detection of the windthrow area allows the economic and ecological damage to be detected as soon as possible (Havašová et al., 2017). The size of windthrow areas and environmental parameters are also determined by used remote sensing data (Einzmann et al., 2017; Vaglio Laurin et al., 2021).

In this study, Kastamonu Regional Directorate of Forestry, which has a windthrow natural disaster every year in Türkiye, was preferred. Normalized Difference Fraction Index (NDFI) was calculated from the Sentinel-2A satellite image on the Google Earth Engine platform (GEEp) to detect windthrow sizes. From the NDFI calculated images, the borders of the windthrow segments were drawn in shp. format. The relationship between the windthrow areas obtained in shp. data and environmental parameters were determined using random sampling method. The regression tree model was used to determine the relationship between windthrow areas and environmental parameters. In the regression tree model used, Akaike information criterion (AIC) was used to determine the most suitable model. Correlation Coefficient (R2) was calculated to accuracy assessment for the model. The Correlation Coefficient (R2) was calculated for model validation. The best model was reached when the AIC value calculated for each environmental parameter was minimum value. Error margins for the model were determined by calculating Mean Absolute Error (MAE) and Relative Root Mean Square Error (RRMSE). This study detected the relationship between the sizes of windthrow areas that occurred in the Kastamonu Forest Regional Directorate between 2017-2021 and environmental parameters. When the results obtained are considered in forest silvicultural interventions planning, it will enable better outcomes for the sustainability of forests.

## 2. Material and Method

### 2.1. Study Area

The Kastamonu Forest Regional Directorate was located in the Western Black Sea Region in the Western Black Sea Section, covering an area of 12,861.12 km². Forests cover an area of 8,191.94 km² in Kastamonu. The Kastamonu Forest Regional Directorate is situated between 32º 44' 59" - 34º 36' east longitudes and 40º 50' 4" - 42º 1' 12 north latitudes. The elevation ranges from 0 to 2578 meters. The northern slopes of the Ilgaz Mountains (2578 m) rising in the south of Kastamonu provide a suitable environment for the growth of moist forests consisting of Oriental beech (*Fagus orientalis*), Nordmann fir (*A. nordmanniana*), Scots pine (*Pinus sylvestris*), and sessile oaks (*Q. Petraea*). In the low elevations of the southern slopes, there were forested areas consisting of Turkish pine *(Pinus brutia*), Turkey oak (*Q. cerris*), pubescent oak (*Q. pubescens*), Valonia oak (*Quercus infectoria*) and juniper species *(Juniperus excelsa*, *J. foetidissima*) (Günal, 2013). The location map of the study area was provided in Figure 1.

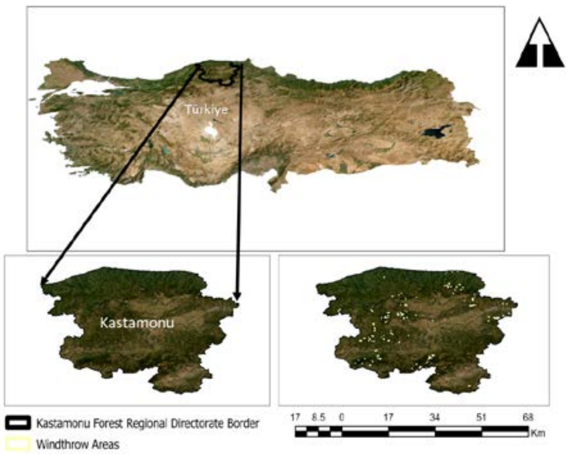



Figure 1. Forest Regional Directorate border map of Kastamonu

### 2.2. Method

The Kastamonu Forest Regional Directorate area in Türkiye, where windthrow cases are frequent, was chosen for the study. Pre- and post-event Normalized Difference Fraction Index (NDFI) was calculated from Sentinel-2A satellite imagery on the Google Earth Engine platform (GEEp) to detect windthrow areas. The calculated NDFI was used to determine the location and size of the windthrow. A database was created for the locations using a random sampling method for the identified windthrow areas. In order to determine the relationship between the sizes of windthrow areas and environmental parameters, which is the aim of the study, site index, slope, elevation, distance to road, wind speed, precipitation, soil texture, root type and forest stand type (pure and mixed) maps were created. Data for the randomly sampled windthrow areas were collected from the created environmental parameters. After the stage of detecting windthrow data, test of normality, Pearson correlation analysis and regression tree were applied to determine the relationship between windthrow sizes and environmental parameters. Akaike information criterion (AIC) was used in selecting the most suitable model for determining the relationship between windthrow sizes and environmental parameters. Upon selecting the most suitable model, a regression tree was created, and the accuracy of the model was determined using the Correlation Coefficient ($R^2$), while error margins of the model were identified using Mean Absolute Error (MAE) and Relative Root Mean Square Error (RRMSE). The workflow of the study was presented in Figure 2.

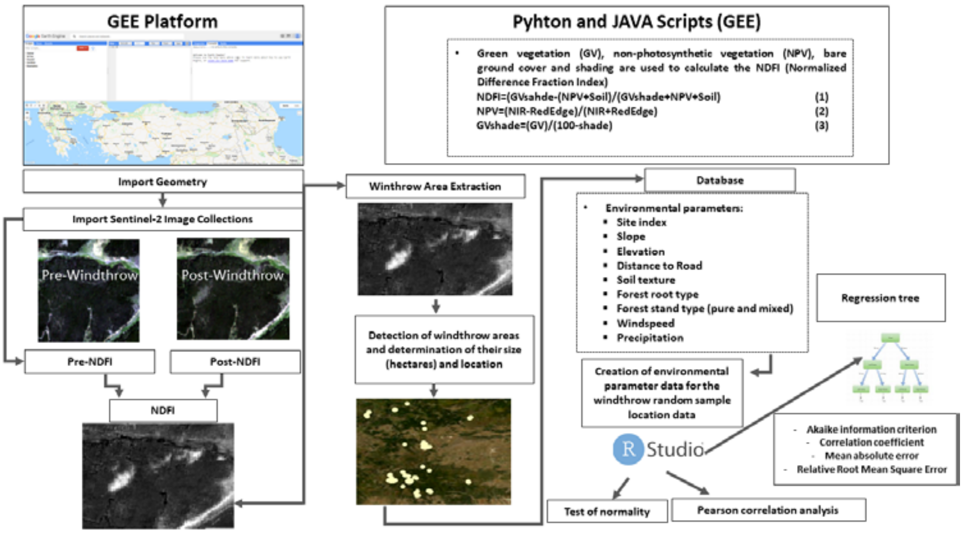



Figure 2. Workflow of the study

### 2.2.1. Remote sensing data

In the study conducted, the aim was to detect windthrow areas using the extraordinary yield reports from the Kastamonu Forestry Regional Directorate. The locations of the data in the extraordinary yield reports were determined by calculating the Normalized Difference Fraction Index (NDFI) from the Sentinel-2A is an earth observation satellite with a spatial resolution of 10-60 meters. Sentinel-2A has 13 bands and its scanning width is 290 kilometers. In this study, Sentinel-2A satellite was used and NDFI was calculated to determine the windthrow locations and sizes. Green vegetation (GV) and non-photosynthetically active vegetation (NPV) were used to calculate NDFI from Sentinel-2A satellite imagery. The pixel value of NDFI used to detect windthrow areas varies between -1 and 1. According to the NDFI result, values approaching -1 identify forest areas and values approaching +1 identify deforested areas (Liu et al., 2011; Wen, 2014; Souza et al., 2005). The formula used to calculate the NDFI is given in (1) and the formulas used to calculate the GV and NPV are given in (2, 3).

$$NDFI = (GVsahde - (NPV + Soil)/(\text{GVshade} + (NPV + Soil)) \quad (1)$$

$$NPV = (\rho NIR - \rho \text{RedEdge})/(\rho NIR + \rho \text{RedEdge}) \quad (2)$$

$$GVshade = (GV)/(100 - shade) \quad (3)$$

### 2.2.2. Environmental variables

During the production stage of environmental parameters, Digital Elevation Model (DEM) was downloaded from the EarthData database (Tsuchida et al., 2020). Slope (degree) data was generated from the DEM data with the help of ArcMap software. Euclidean distance analysis was applied to the road data at the boundary of Kastamonu Forest Regional Directorate to determine the distances of windthrow areas to roads. Site index data was produced from the General Directorate of Forestry's management database. Data in the '0' category of the site index data were not considered because data in the '0' category represent unhealthy forests. Codes were assigned to tree species in the General Directorate of Forestry's management data for the creation of the root type and forest stand type (pure and mixed) database. An 'excel macro' code was written to produce the root type and forest stand type (pure and mixed) database. The database generated in Excel macro was joined to ArcMap software and converted to raster data format. Soil texture types for the study area were determined from USDA (U.S. DEPARTMENT OF AGRICULTURE) TEXTURE-CLASS in GEEp. Windspeed and average precipitation 5 days prior to the windthrow event parameters were produced using data from the National Oceanic and Atmospheric Administration (NOAA) in GEEp. The windthrow date in the extraordinary yield reports of Kastamonu Forest Regional Directorate was taken into account for the production of windspeed and average precipitation 5 days prior to the windthrow event data. The codes and explanations for categorical data of root type, forest stand type (pure and mixed), and soil texture types were given in Table 1.

Table1. Forest root type, forest stand type (pure and mixed) soil texture type and site index code information

| Soil Texture | | Forest Root Types | | Stand Type (pure and mixed) | | Site Index | |
|---|---|---|---|---|---|---|---|
| 1 | Clay | 551 | Tap Root | 100 | Coniferous Pure | I | 1 |
| 2 | Silty Clay | 552 | Hearth Root | 200 | Latifolius Pure | II | 2 |
| 4 | Clay Loam | 553 | Tap Root – Hearth Root | 300 | Coniferous + Coniferous Mix | III | 3 |
| 6 | Loam | 554 | Hearth Root – Tap Root | 400 | Coniferous + Latifolius Mix | IV | 4 |
| 7 | Sandy Clay Loam | 555 | Tap Root - Tap Root | 500 | Latifolius + Coniferous Mix | V | 5 |
| 9 | Silty Loam | 556 | Hearth Root – Hearth Root | 600 | Latifolius + Latifolius Mix | | |

### 2.2.3. Statistical analysis

The Kolmogorov-Smirnov test was used to determine whether the sizes of windthrow areas exhibit a normal distribution at the statistical stage. After the applied test revealed that the windthrow size data did not show a normal distribution in the areas, Cook's distance analysis was conducted to ensure that it does not affect the model's success. The windthrow size data identified through Cook's Distance analysis was excluded from the modeling stage. Prior to the modeling stage, a Pearson correlation analysis was applied among the environmental parameters. The applied Pearson correlation analysis determined whether there is high correlation among the environmental parameters. Regression tree analysis was conducted between windthrow sizes and environmental parameters. Akaike information criterion (AIC) was calculated for selecting the regression tree model. The AIC formula was given in (4).

$$AIC = n.\ln\left(\frac{RTK}{n}\right) + 2k \tag{4}$$

$RTK$ provides the sum of squared regression residuals to determine the error variance. In the formula, $n$ and $k$ represent the number of data points used in developing the model and the number of coefficients in the model. A low AIC value indicates that the model's success will be high (Demyanov et al., 2012; Aho et al., 2014).

Regression tree technique has been among non-parametric tests. The regression tree divides independent variables into homogeneous subgroups based on the dependent variables. In the formation of subgroups, independent variables are structured in a hierarchical order in the form of a tree. Intermediate nodes are created in the generated regression tree, and these intermediate nodes provide critical values for the independent variables. In the regression tree, there were lines from the root node (first node) to the leaves (last node). The regression tree method could model both categorical and continuous variables (Breiman et al., 1984; Navarrate and Espinosa, 2011). The differentiation between trees in a regression tree has been done based on the minimization of the total variance according to the "reduce sum of squares of residuals algorithm" (Breiman et al., 1984). Minimization at each node in the regression tree method has been solved as in formula (5).

$$argmin_{xj \le x_j^R, j=1,\dots M}[P_l Var(Y_l) + P_r Var(Y_r)] \tag{5}$$

In the formula, $P_l$ and $P_r$ represent the probabilities of the right and left nodes, while $M$ represents the number of variables in the training set. The variables used in the model, $j$ and $xj$, $x_j^R$ determine the best separation point of the variable $Var(Y_l)$ and $P_r Var$ in the formula are responsible vectors for the resulting right and left nodes. By performing optimal separation of the data with $xj \le x_j^R, j = 1, \dots M$, threshold values have been determined (Breiman et al., 1984). The "reduce sum of squares of residuals algorithm" used in regression trees is similar to the Gini splitting rules. If the value of class " $k$ " is 1 and the values of other classes are 0, impurity measurement is used (Özkan, 2012). The formula for impurity measurement was given in (6).

$$i(t) = 1 - \sum_{k=1}^{K} p^2\left(\frac{k}{t}\right) \tag{6}$$

In the formula, $p^2\left(\frac{k}{t}\right)$ represents the conditional properties of class k within node $t$, where $K$ was the number of classes, $k$ was the class index, and $t$ was the node index (Özkan, 2012).

### 2.2.4. Model performance measures

Statistical calculations were performed to determine the accuracy of the regression tree model used to determine the relationship between windthrow size and environmental parameters. Correlation coefficient ($R^2$) (Wang et al. 2020), mean absolute error (MAE) (Karunasingha, 2022) and the Relative Root Mean Square Error (RRMSE) were calculated to evaluate the performance of the model. Low MAE and RRMSE show that the model has a small margin of error, while the success of the model was high when $R^2$ approaches 1 (Wang et al., 2020; Ćalasan et al., 2020; Karunasingha, 2022). Equations (7,8,9) were given for statistical calculations in which the success criteria of the model were determined.

$$R^2 = \left( \frac{\sum_{i=1}^{n} (O_i - \overline{O})^2 . (P_i - \overline{P})}{n.\sigma_O.\sigma_P} \right)^2 \tag{7}$$

$$MAE = 1 - \left( \frac{\sum_{i=1}^{n} |P_i - O_i|}{n} \right) \tag{8}$$

$$RRMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} / \sqrt{\sum_{i=1}^{n} O_i^2} \tag{9}$$

In the Equations used for statistical calculations, *n* is the total number of windthrow sites, $P_i$ is the estimated values of the environmental parameters, Oi is the values of the environmental parameters detected at the windthrow areas. $\overline{P}$ is the mean of $P_i$, while σP is the standard deviation of $P_i$. In the equations σO is the standard deviation of $O_i$ and $\bar{O}$ was represent of the detected values of environmental parameters mean.

**3. Results**

The dates and location information of the windthrows that occurred in the Kastamonu Forest Regional Directorate between 2017-2021 were obtained from extraordinary yields reports. A total of 169 windthrow data were identified from the extraordinary yield's reports. The dates and location information of the windthrows obtained from the extraordinary yield's reports were used to determine the windthrow sizes by calculating the NDFI from the Sentinel-2A satellite imagery. The detected of windthrow area and sizes from NDFI was presented in Figure 3.

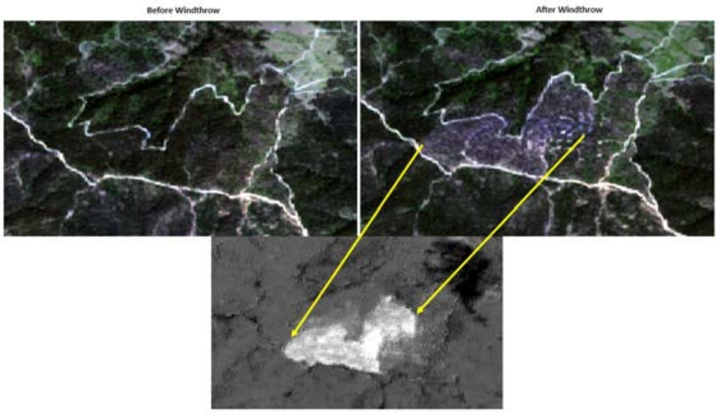



Figure 2. Detection of windthrow areas and sizes using NDFI

According to the extraordinary yield's reports of the Kastamonu Forest Regional Directorate, there have been a total of 169 different windthrow incidents. However, 132 different windthrow areas were identified from the Sentinel-2A satellite imagery. The reason why 37 windthrow areas could not be detected is that they occurred in forested areas smaller than 6.69 hectares. By calculating the NDFI in the Kastamonu Forest Regional Directorate, it was determined that areas minimum of 6.69 hectares to a maximum of 125 hectares were affected. The map showing the locations of the windthrows was provided in Figure 4.

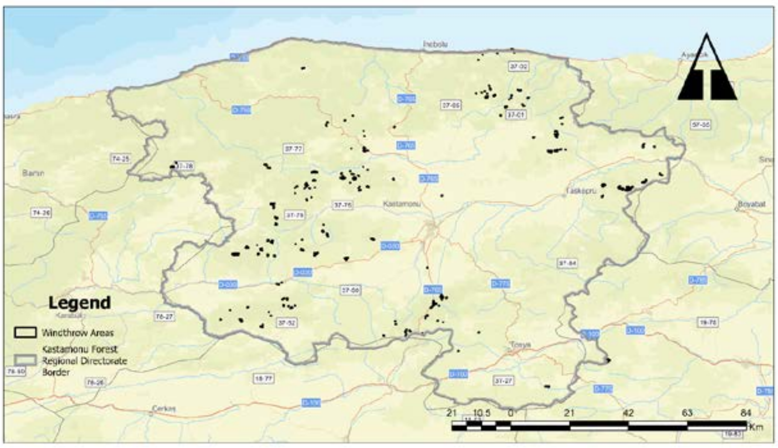



Figure 4. Windthrow areas detected by NDFI between 2017-2021

After the detect of windthrow locations and sizes using NDFI, maps of 9 different environmental parameters the Kastamonu Forest Regional Directorate (elevation, slope, forest tree root type, stand type (pure and mixed), site index, soil texture, distance to road, maximum wind speed and total precipation for the 5 days prior to the windthrow) have been generated for the used modeling stage. The maps of the environmental parameters created for the Kastamonu Forest Regional Directorate were given in Figure 5.

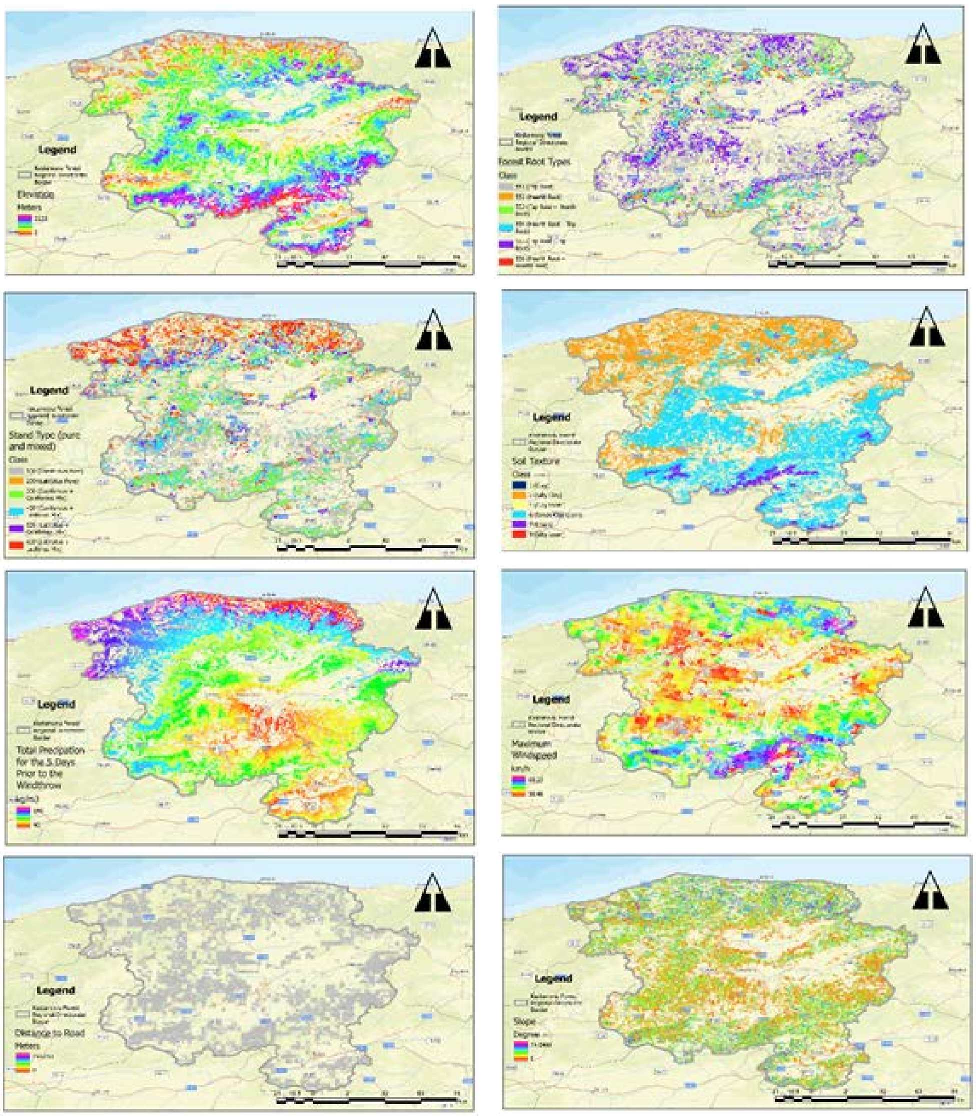



Figure 5. Enviromental parameteters used in the modeling stage

Parameters for the created of environmental parameters were not generated for the areas with a site quality classification of '0' in forest management plans. This is because there are no productive forests in locations classified as site index '0'. According to the site index classification map of Kastamonu Regional Directorate of Forestry, it was determined that the maximum site quality class was '3' and the minimum '1'. When the elevation map of Kastamonu Regional Directorate of Forestry was examined, it was identified that the upper limit of the forest reached up to 2230 meters. On the other hand, the lowest elevation is 0 meters. In the slope map of Kastamonu Regional Directorate of Forestry, the highest slope in healthy forests is 72 degrees and the lowest slope is 0 degrees. In the distance to road parameter map created for the windthrow areas, it was determined that the highest wind throw was 2597.93 meters, and the lowest wind throw was 0 meters. Other environmental parameters used in the modeling phase are maximum wind speed and windthrow, along with the total precipitation for the 5 days prior to the windthrow. Maximum wind speed and total precipitation for the 5 days prior to the windthrow amount were obtained from the National Oceanic and Atmospheric Administration (NOAA) data. The wind speed and total precipitation for the 5 days prior to the windthrow map was created by determining the maximum wind speed and daily precipitation amount at the location of the windthrow day by the Euclidean Distance analysis. When the map of maximum wind speed belonging to the Kastamonu Forest Regional Directorate determined that the maximum wind speed is 89.89 km/h and the minimum is 36.46 km/h. The other map, total precipitation for the 5 days prior to the windthrow, detected that the maximum total precipitation was 146 kg/m3 and the minimum was 43 kg/m3. Another parameter used in the modeling phase is texture. The texture map was produced from the U.S. DEPARTMENT OF AGRICULTURE (USDA) in GEEp. According to the soil texture map of healthy forests in the Kastamonu Forest Regional Directorate determined that the soil texture is mostly Sandy Clay Loam and least silty clay. Forest root types and stand type (pure and mixed) map, another environmental parameter, were produced from the forest management plan of the General Directorate of Forestry in Türkiye. In order to create the Forest root types and stand type (pure and mixed) map, codes were written in excel makro and classification was made for each species and species groups. In the classification made, the mixture status and forest root types were determined prioritizing dominant species. The identified mixture status and forest root types were converted into raster data format by ArcMap. It was determined that coniferous pure forests are more dominant in the Kastamonu Forest Regional Directorate. In the Forest root types map produced, the areas where heart roots are less dominant than taproots are found to be the least. According to the other map created, the stand type (pure and mixed) map determined that coniferous pure were found the dominant. It was determined that forest areas where latifolius species are dominant and coniferous species are scarce covering the least area.

The aim was to determine the relationship between the sizes of windthrow areas exposed to wind in the Kastamonu Forestry Regional Directorate and environmental parameters. The sizes and locations of windthrow areas were determined by calculating NDFI. In order to determine whether the sizes of windthrow areas exhibited a normal distribution, the Shapiro-Wilk normal distribution test was applied. According to the Shapiro-Wilk test result, with a p-value < 0.032, it was determined that the data did not show a normal distribution. The windthrow areas identified as outliers observation were determined according to the Shapiro-Wilk test. The Shapiro-Wilk normal distribution test result plot for windthrow areas was given Figure 6.

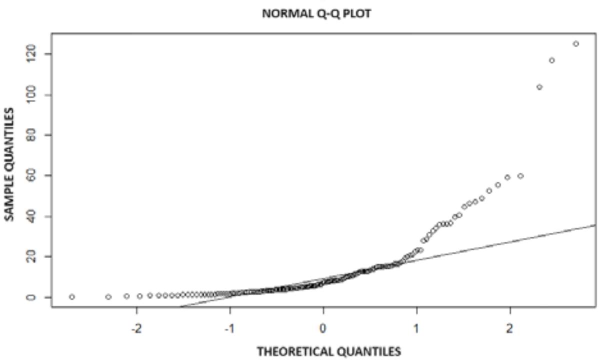



Figure 6. Plot of the Shapiro-Wilk test Results

According to the Shapiro-Wilk normal distribution test plot graph, 3 windthrow areas were found to be outliers. Cook's distance analysis was applied to identify areas with outlier observations. Cook's distance analysis result was given in Figure 7.

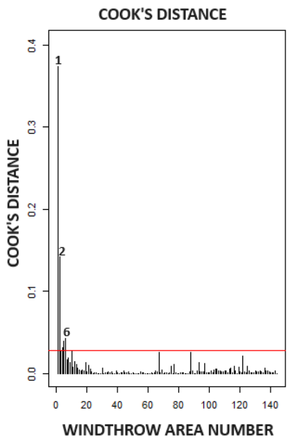



Figure7. Cook's distance analysis applied to windthrow areas

According to Cook's distance analysis, outlier observations were detected in the 1st, 2nd and 6th windthrow areas. Outlier observations were removed in the analysis stage in order not to affect the success of the model. After the outlier observations were removed from the analysis as a result of Cook's distance analysis, the size of the windthrow areas and the distribution of environmental parameters were determined. The graphs of the size of the windthrow areas and the distribution of environmental parameters were given in Figure 8.

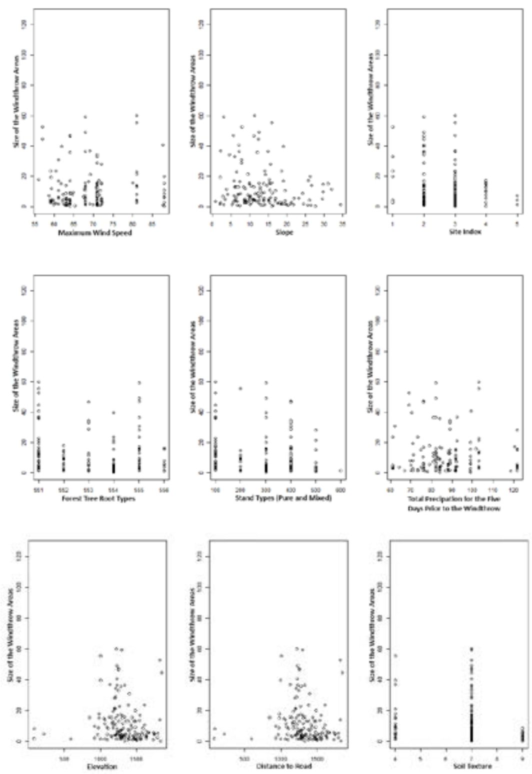



Figure 8. Distribution of environmental parameters by size of areas affected by windthrow

According to the plots in Figure 8, it was determined that the areas exposed to windthrow were more frequent in wind speeds between 58-73 km/h. In terms of another environmental parameter slope, it was found that windthrow was more prevalent in slopes between 0°-23°, and in terms of site index, windthrow was more frequent in the 2nd and 3rd site index, which represent the productivity of the growing environment. Based on the tree root type used in the modeling, it was observed that windthrow is more common in forests with 551 (Tap Root) tree species and 555 (Tap Root - Tap Root) mixed forests. According to the pure mixed parameter windthrow is more prevalent in forests with 100 (Coniferous Pure) and 300 (Coniferous + Coniferous Mix) tree species. When the total precipitation for the 5 days prior to the windthrow was examined, it was found that degradation was more frequent at elevations between 1070-1490 meters and in regions where precipitation was between 70-104 mg/m3. In terms of the distance to road parameter for windthrow more damage occurred in areas 1200-1450 meters away from the road, and based on the soil texture parameter, it was determined that more damage occurred in areas with a Sandy Clay Loam (7) texture. The distributions of the environmental parameters used in the modeling phase are provided in Table 2.

The main reason for the higher occurrence of windthrow areas between 1070 and 1490 meters is the presence of more stands with a high site index. When examining the table, it can be seen that stands with a site index of II account for 34% of the distribution. In other elevation ranges, 0-1071 m, the site index is 10%, and in the 1490-2230 m elevation range, it shows a distribution of 11%. Therefore, windthrow areas are more prevalent at 1070 and 1490 meters elevation level. Additionally, the elevation range where windspeed is highest is between 1070 and 1490 meters. In this elevation range, the percentage of windspeed exceeding 56 km/h is 55%. In other elevation ranges, the percentage of windspeed exceeding 56 km/h is 25% for both the 0-1070 m and 1490-2230 m ranges. The high site index in this elevation range has also contributed to the increased occurrence of windthrow.

Following the examination of the sizes of areas affected by windthrow and the distributions of environmental parameters, the modeling phase has been initiated. Before moving on to the modeling stage, a Pearson correlation analysis was conducted to determine the relationships between environmental parameters and identify variables showing high correlation. The result of the Pearson correlation analysis was given Figure 9.

According to the result of the Pearson correlation analysis, no parameter exceeding a high correlation coefficient of 0.8 was identified. Due to the not detected of high correlation among environmental parameters, the modeling stage was initiated. In the modeling stage, the regression tree method was used. In order to determine the best model in the regression tree, the Akaike information criterion (AIC) was calculated. Environmental parameters with low importance coefficients in the AIC calculation were excluded from the AIC calculation. The AIC value of 128.76 was achieved when the maximum windspeed, slope and site index were used. When other environmental parameters were included, the AIC value increased and the model's success, as shown by the correlation coefficient ($R^2$) decreased. The statistical results of the windspeed, slope, and site index used in the modeling stage were provided in Table 3.

Table 2. Percentage distributions of environmental parameters belonging to the Kastamonu Forest Regional Directorate

| Elevation (m) | Distribution (%) | Site index | Distribution (%) | Windspeed km/h | Distribution (%) | Precipitation kg/m$^2$ | Distribution (%) |
|---|---|---|---|---|---|---|---|
| 0-1070 | 20 | 1 | 15 | 34-40 | 27 | 32-80 | 19 |
| | | 2 | 10 | 41-47 | 40 | 81-130 | 9 |
| | | 3 | 10 | 48-55 | 8 | 131-180 | 30 |
| | | 4 | 35 | 56-63 | 9 | 181-230 | 22 |
| | | 5 | 30 | >64 | 14 | 231-252 | 20 |
| 1070-1490 | 44 | 1 | 12 | 34-40 | 20 | 32-80 | 25 |
| | | 2 | 34 | 41-47 | 7 | 81-130 | 32 |
| | | 3 | 29 | 48-55 | 13 | 131-180 | 10 |
| | | 4 | 10 | 56-63 | 21 | 181-230 | 13 |
| | | 5 | 15 | >64 | 34 | 231-252 | 10 |
| 1490-2230 | 36 | 1 | 12 | 34-40 | 24 | 32-80 | 9 |
| | | 2 | 11 | 41-47 | 38 | 81-130 | 17 |
| | | 3 | 18 | 48-55 | 13 | 131-180 | 18 |
| | | 4 | 31 | 56-63 | 11 | 181-230 | 23 |
| | | 5 | 28 | >64 | 14 | 231-252 | 33 |

| Elevation (m) | Distribution (%) | Root type | Distribution (%) | Elevation | Texture | Distribution (%) |
|---|---|---|---|---|---|---|
| 0-1070 | 20 | Tap root | 10 | 0-1650 | clay | 11 |
| | | Hearth root | 6 | | siltyclay | 42 |
| | | Tap root-hearth root | 9 | | clayloam | 9 |
| | | Hearth root-tap root | 9 | | sandyclayloam | 10 |
| | | Tap root - tap root | 25 | | loam | 19 |
| | | Hearth root – hearth root | 41 | | siltyloam | 11 |
| 1070-1490 | 44 | Tap root | 33 | 1650-2613 | clay | 9 |
| | | Hearth root | 12 | | siltyclay | 11 |
| | | Tap root-hearth root | 11 | | clayloam | 22 |
| | | Hearth root-tap root | 9 | | sandyclayloam | 43 |
| | | Tap root - Tap root | 25 | | loam | 7 |
| | | Hearth root – hearth root | 10 | | siltyloam | 8 |
| 1490-2230 | 36 | Tap root | 19 | 1650-2613 | clay | 10 |
| | | Hearth root | 9 | | siltyclay | 28 |
| | | Tap root-hearth root | 11 | | clayloam | 10 |
| | | Hearth root-tap root | 6 | | sandyclayloam | 14 |
| | | Tap root - tap root | 25 | | loam | 16 |
| | | Hearth root – hearth root | 20 | | siltyloam | 14 |

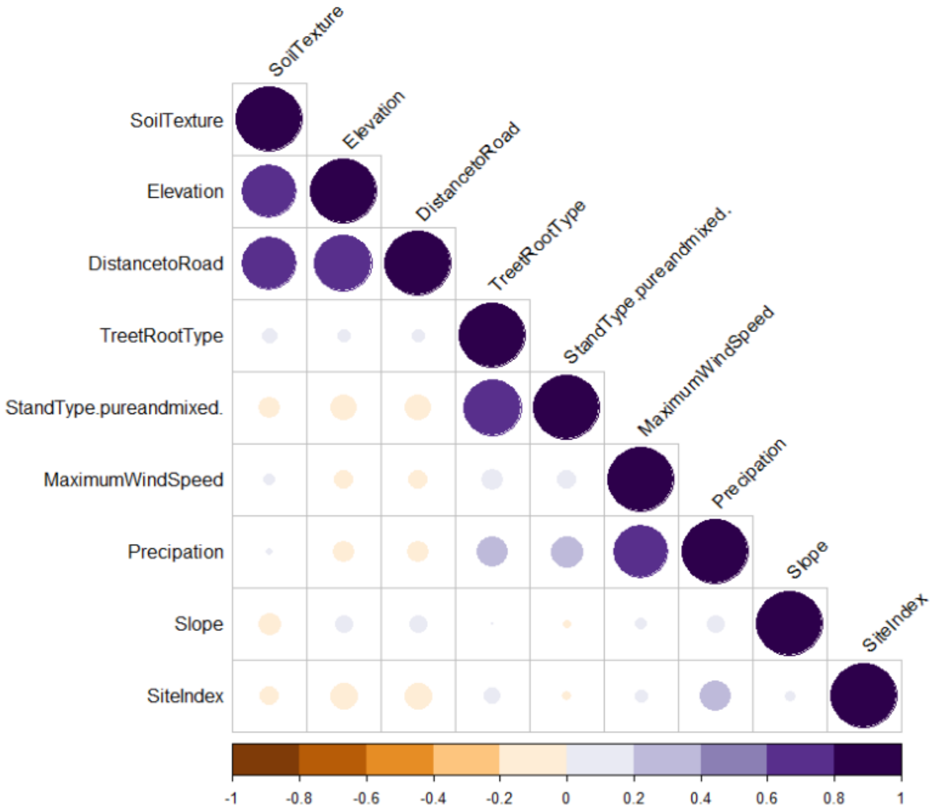



Figure 9. Result of the Pearson correlation analysis

Table 3. Statistical results of the parameters used in the modeling

| Parameters | Standard Error | t value | Pr(>\|t\|) |
|---|---|---|---|
| Maximum Wind Speed | 1.23 | 2.15 | 0.04 |
| Slope | 1.29 | 2.11 | 0.06 |
| Site Index | 1.21 | 2.30 | 0.02 |

According to the statistical results of the environmental parameters used in the modeling, the lowest standard error was found in the site index highest slope. When evaluating the environmental parameters based on the t-value, all environmental parameters had t≥0.5, indicating that there was no significant difference between the means of the parameters. The abbreviation Pr(>t) in the model output represents the probability of observing a value equal to or greater than t. A small Pr value indicates that it is unlikely to observe a random relationship between the parameters. According to the statistical results in Table 2, it was determined that the Pr value for each environmental parameter was low compared to the t-value. To assess the success of the model created with maximum windspeed, site index and slope, the Correlation Coefficient ($R^2$), Mean Absolute Error (MAE), and Relative Root Mean Square Error (RRMSE) were calculated. The calculated statistical findings for the model output were presented in Table 4.

Table 4. Statistical results of the model

| Correlation Coefficient ($R^2$) | Mean Absolute Error (MAE) | Relative Root Mean Square Error (RRMSE) |
|---|---|---|
| 0.81 | 0.29 | 3.02 |

During the evaluation stage of the model, $R^2$ varies between 0 and 1. As $R^2$ approaches 1, the model's success increases. According to the statistical results of the regression model, the $R^2$ value is 0.81, indicating that the model result is in a very high correlation class. MAE and RRMSE provide information about the model's error margins. The MAE result is 0.29 and the RRMSE result is 3.02, indicating that the model's error margin is low. The regression tree of the model result was given Figure 10.

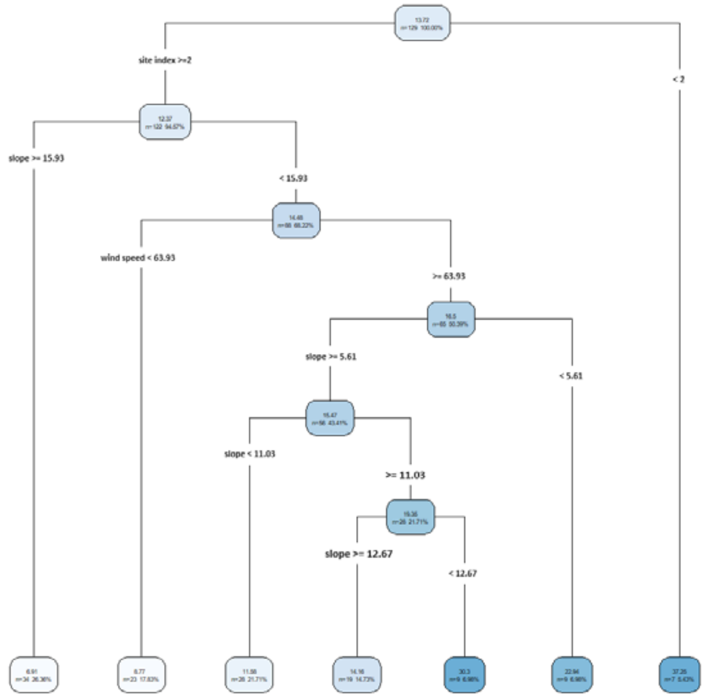



Figure 10. Regression tree result of the relationship between the sizes of windthrow areas and environmental parameters

In the regression tree model based on maximum wind speed, slope, and site index, the relationships between 129 windthrow areas size were determined in relation to the environmental parameters. Between 2017-2021, windthrow affected 7 areas in the I site index class, with size ranging from 30.3 to 37.25 hectares. The largest area affected by windthrow occurred when the site index was in the 1st class and the maximum wind speed exceeded 63.93 km/h. In areas with II, III, IV and V site index, windthrow affected areas ranged from 6.91 to 30.3 hectares, totaling 122 windthrow areas. In areas where the slope was greater than 15.93°, a total of 34 windthrow instances occurred, with area sizes ranging from 6.91 to 8.77 hectares. In areas where the slope was less than 15.93° and the maximum wind speed was less than 63.93 km/h, there were 23 instances of windthrow, with sizes ranging from 8.77 to 11.58 hectares. In cases where the slope was less than 15.93 ° and the maximum wind speed was greater than 63.93 km/h, there were 65 instances of windthrow. In areas where the maximum wind speed exceeded 63.93 km/h and the slope was greater than 5.61°, a total of 56 windthrow instances occurred, with degradation ranging from 11.85 to 30.3 hectares.

**4. Discussion**

In the regression tree model used in this study, which examined the relationship between windthrow sizes and environmental parameters, the highest separation was realized in slope. Windthrow occurred most frequently in areas where the slope was more than 15.93°. However, the areas with the lowest degredation hectare were those with slopes above 15.93°. An increase in windthrow rates was detected in locations where the slope was less than 12.67. There are studies by Çınar et al. (2023), Ulanova (2000), Wohlgemuth et al. (2017), Schmoeckel and Kottmeler, (2008) and Schütz et al. (2006) in which the relationship between windthrow and environmental parameters was determined. Çınar et al. (2023), Ulanova (2000) and Wohlgemuth et al. (2017) found that windthrow cases increase in frequency with increasing slope. According to the results of the regression analysis model, in areas where the slope is more than 15.93° degrees, the number of windthrow cases is high but the size is quite small. Schmoeckel and Kottmeler (2008) and Schütz et al. (2006), other studies that found a relationship between slope and windthrow, found that windthrow decreased in areas with steep slopes. Schmoeckel and Kottmeler (2008) and Schütz et al. (2006) stated that an increase will be observed as we move from locations where the slope is in the steep class to locations where the slope decreases.

In the modeling stage, another parameter used site index, made a distinction in the regression tree with windthrow sizes. Previous studies conducted by Harris (1999), and Mitchell et al. (2001) have researched the relationship between windthrow and site index. These studies have determined that when the site index was "I," more windthrow incidents were likely to occur. They have also indicated that susceptibility to windthrow decreases as the site index class rises to "V." In a different study, Ruel (2000) mentioned that the intensity of windthrow would increase as tree heights increase. Ruel (2000), identified the relationship between changes in tree heights and diameters and windthrow using the ForestGales model, stated that an increase in tree heights would cause more damage to trees and consequently increase the volume of trees affected in the area. In the regression tree used in the modeling, it was determined that windthrow sizes increased when the site index in windthrow areas was "I" leading to the highest degradation in the forest. In areas where the site index was " II, III," "IV," and "V," the frequency of windthrow occurrences was high, but the sizes are low.

Windspeed, which is the most important parameter in modeling and in the formation process of windthrow, is the other parameter that distinguishes in the regression tree used in modeling. Dieler et al. (2017) and Zeller et al. (2023) stated that with high wind speed, there will be mass tree destruction. On the other hand, research conducted by Taeroe et al. (2019) and Thorn et al. (2016) stated that high wind speed leading to windthrow causes disruption of the soil nutrient mineral chain, emergence of insect damages and serious harm to plant species. In this study, it was observed that there is a significant increase in windthrow sizes when wind speed exceeds 63.93 km/h. In addition, when the site index is "I" and wind speed exceeds 63.93 km/h, windthrow size reaches the highest levels.

**5. Conclusion**

In this research, which was conducted for the first time in the literature, windthrow areas occurring in Kastamonu Forestry Regional Directorate in 2017-2021 were determined by calculating NDFI from Sentinel-2A satellite image. The size of each calculated windthrow area was determined in hectares. The detected windthrow areas were modeled with the regression tree method using environmental parameters. According to the results of the regression tree model in Kastamonu Forestry Regional Directorate, the most important parameters were maximum wind speed, site index and slope. The results of the regression tree method showed that in Kastamonu Forestry Regional Directorate, the windthrow sizes were greater in locations where the site index was “I” in these locations, if the wind speed exceeded 63.93 km/h. In locations where the site index was “II , III”, “IV” and “V”, the amount of size affected by windthrow decreased when the wind speed was less than 63.93 km/h and the slope was more than 15.93$^{o}$. In line with the maps created, area-based conservation studies should be carried out and silvicultural interventions should be planned more carefully. In addition to silvicultural interventions, it would be more appropriate to plant latifolius species with flexible body structure in afforestation works in locations where windthrow areas are present.

**References**

Aho, K., Derryberry, D., & Peterson, T. (2014). Model selection for ecologists: the worldviews of AIC and BIC. Ecology, 95(3), 631-636.

Alfaro-Alejo, R., Paredes-Mamani, R. P., Montenegro-Gambini, J., Belizario-Quispe, G., & Flores-Condori, E. (2021, November). Geo-hydrological risk awareness and disaster preparedness in a mountainous area of Southern Peru vulnerable to disaster. In IOP Conference Series: Earth and Environmental Science (Vol. 906, No. 1, p. 012125). IOP Publishing.

Anyomi, K. A., Mitchell, S. J., Perera, A. H., & Ruel, J. C. (2017). Windthrow dynamics in boreal Ontario: a simulation of the vulnerability of several stand types across a range of wind speeds. Forests, 8(7), 233.

Breiman, L., & Ihaka, R. (1984). Nonlinear discriminant analysis via scaling and ACE. Davis One Shields Avenue Davis, CA, USA: Department of Statistics, University of California.

Ćalasan, M., Aleem, S. H. A., & Zobaa, A. F. (2020). On the root mean square error (RMSE) calculation for parameter estimation of photovoltaic models: A novel exact analytical solution based on Lambert W function. Energy conversion and management, 210, 112716.

Canham, C. D., Papaik, M. J., & Latty, E. F. (2001). Interspecific variation in susceptibility to windthrow as a function of tree size and storm severity for northern temperate tree species. Canadian Journal of Forest Research, 31(1), 1-10.

Cucchi, V., Meredieu, C., Stokes, A., de Coligny, F., Suarez, J., & Gardiner, B. A. (2005). Modelling the windthrow risk for simulated forest stands of Maritime pine (Pinus pinaster Ait.). Forest Ecology and Management, 213(1-3), 184-196.

Çınar, T., Özdemir, S., & Aydın, A. (2023). Identifying areas prone to windthrow damage and generating susceptibility maps utilizing a novel vegetation index extracted from Sentinel-2A imagery. Journal of the Indian Society of Remote Sensing, 51(12), 2391-2402.

Dale, V. H., & Beyeler, S. C. (2001). Challenges in the development and use of ecological indicators. Ecological indicators, 1(1), 3-10.

Demyanov, S., Bailey, J., Ramamohanarao, K., & Leckie, C. (2012, November). AIC and BIC based approaches for SVM parameter value estimation with RBF kernels. In Asian Conference on Machine Learning (pp. 97-112). PMLR.

Dhubháin, Á. N., & Farrelly, N. (2018). Understanding and managing windthrow. COFORD Connects, Silviculture/Management, (23).

Dieler, J., Uhl, E., Biber, P., Müller, J., Rötzer, T., & Pretzsch, H. (2017). Effect of forest stand management on species composition, structural diversity, and productivity in the temperate zone of Europe. European Journal of Forest Research, 136, 739-766.

Einzmann, K., Immitzer, M., Böck, S., Bauer, O., Schmitt, A., & Atzberger, C. (2017). Windthrow detection in European forests with very high-resolution optical data. Forests, 8(1), 21.

Griess, V. C., & Knoke, T. (2011). Growth performance, windthrow, and insects: meta-analyses of parameters influencing performance of mixed-species stands in boreal and northern temperate biomes. Canadian Journal of Forest Research, 41(6), 1141-1159.

Hanewinkel, M., Hummel, S., & Albrecht, A. (2011). Assessing natural hazards in forestry for risk management: a review. European Journal of Forest Research, 130, 329-351.

Harris, A. S. (1999). Wind in the forests of southeast Alaska and guides for reducing damage. Gen. Tech. Rep. PNW-GTR-244. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 63 p, 244.

Havašová, M., Ferenčík, J., & Jakuš, R. (2017). Interactions between windthrow, bark beetles and forest management in the Tatra national parks. Forest Ecology and Management, 391, 349-361.

Ingold, T. (2005). The eye of the storm: visual perception and the weather. Visual studies, 20(2), 97-104.

Karunasingha, D. S. K. (2022). Root mean square error or mean absolute error? Use their ratio as well. Information Sciences, 585, 609-629.

Kautz, M., Meddens, A. J., Hall, R. J., & Arneth, A. (2017). Biotic disturbances in Northern Hemisphere forests–a synthesis of recent data, uncertainties and implications for forest monitoring and modelling. Global Ecology and Biogeography, 26(5), 533-552.

Kerr, J. T., & Ostrovsky, M. (2003). From space to species: ecological applications for remote sensing. Trends in ecology & evolution, 18(6), 299-305.

Kidston, J., Scaife, A. A., Hardiman, S. C., Mitchell, D. M., Butchart, N., Baldwin, M. P., & Gray, L. J. (2015). Stratospheric influence on tropospheric jet streams, storm tracks and surface weather. Nature Geoscience, 8(6), 433-440.

Krišāns, O., Matisons, R., Kitenberga, M., Donis, J., Rust, S., Elferts, D., & Jansons, Ā. (2020). Wind resistance of Eastern Baltic silver birch (Betula pendula roth.) suggests its suitability for periodically waterlogged sites. Forests, 12(1), 21.

Kunert, N., Hajek, P., Hietz, P., Morris, H., Rosner, S., & Tholen, D. (2022). Summer temperatures reach the thermal tolerance threshold of photosynthetic decline in temperate conifers. Plant Biology, 24(7), 1254-1261.

Lundquist, J. D., Wayand, N. E., Massmann, A., Clark, M. P., Lott, F., & Cristea, N. C. (2015). Diagnosis of insidious data disasters. Water Resources Research, 51(5), 3815-3827.

MacDicken, K., Jonsson, Ö., Piña, L., Maulo, S., Contessa, V., Adikari, Y., D'Annunzio, R. (2016). Global forest resources assessment 2015: how are the world's forests changing?.

Maurer, S., & Heinimann, H. R. (2020). Framework for assessing the windthrow risk to Norway spruce forests in Switzerland. European Journal of Forest Research, 139(2), 259-272.

Mayer, H. (1989). Windthrow. Philosophical Transactions of the Royal Society of London. B, Biological Sciences, 324(1223), 267-281.

Mitchell, S. J., Hailemariam, T., & Kulis, Y. (2001). Empirical modeling of cutblock edge windthrow risk on Vancouver Island, Canada, using stand level information. Forest Ecology and Management, 154(1-2), 117-130.

Navarrate, E., & Espinosa, M. (2011). Using the non-parametric classifies CART to model wood density. Journal of Data Science, 9(2), 261-270.

Özkan, K. (2012). Modelling ecological data using classification and regression tree technique (CART). Turkish Journal of Forestry, 13(1), 1-4.

Ruel, J. C. (2000). Factors influencing windthrow in balsam fir forests: from landscape studies to individual tree studies. Forest Ecology and Management, 135(1-3), 169-178.

Sagredo, E. A., Rupper, S., & Lowell, T. V. (2014). Sensitivities of the equilibrium line altitude to temperature and precipitation changes along the Andes. Quaternary Research, 81(2), 355-366.

Schelhaas, M. J., Schuck, A., Varis, S., & Zudin, S. (2003). Database on Forest Disturbances in Europe (DFDE): Technical Description. European Forest Institute.

Schmoeckel, J., & Kottmeier, C. (2008). Storm damage in the Black Forest caused by the winter storm" Lothar"–Part 1: Airborne damage assessment. Natural Hazards and Earth System Sciences, 8(4), 795-803.

Schütz, J. P., Götz, M., Schmid, W., & Mandallaz, D. (2006). Vulnerability of spruce (Picea abies) and beech (Fagus sylvatica) forest stands to storms and consequences for silviculture. European Journal of Forest Research, 125, 291-302.

Scott, R. E., & Mitchell, S. J. (2005). Empirical modelling of windthrow risk in partially harvested stands using tree, neighbourhood, and stand attributes. Forest Ecology and Management, 218(1-3), 193-209.

Seidl, R., & Rammer, W. (2017). Climate change amplifies the interactions between wind and bark beetle disturbances in forest landscapes. Landscape Ecology, 32, 1485-1498.

Sinton, D. S., Jones, J. A., Ohmann, J. L., & Swanson, F. J. (2000). Windthrow disturbance, forest composition, and structure in the Bull Run basin, Oregon, Ecology, 81(9), 2539-2556.

Skłodowski, J. (2020). Two directions of regeneration of post-windthrow pine stands depend on the composition of the undergrowth and the soil environment. Forest Ecology and Management, 461, 117950.

Smiley, E. T., Key, A., & Greco, C. (2000). Root barriers and windthrow potential. Journal of Arboriculture, 26(4), 213-217.

Taeroe, A., de Koning, J. H., Löf, M., Tolvanen, A., Heiðarsson, L., & Raulund-Rasmussen, K. (2019). Recovery of temperate and boreal forests after windthrow and the impacts of salvage logging. A quantitative review. Forest Ecology and Management, 446, 304-316.

Taylor, A. R., Dracup, E., MacLean, D. A., Boulanger, Y., & Endicott, S. (2019). Forest structure more important than topography in determining windthrow during Hurricane Juan in Canada's Acadian Forest. Forest Ecology and Management, 434, 255-263.

Teshome, D. T., Zharare, G. E., & Naidoo, S. (2020). The threat of the combined effect of biotic and abiotic stress factors in forestry under a changing climate. Frontiers in plant science, 11, 601009.

Thorn, A. M., Thompson, J. R., & Plisinski, J. S. (2016). Patterns and predictors of recent forest conversion in New England. Land, 5(3), 30.

Ulanova, N. G. (2000). The effects of windthrow on forests at different spatial scales: a review. Forest ecology and management, 135(1-3), 155-167.

Vaglio Laurin, G., Puletti, N., Tattoni, C., Ferrara, C., & Pirotti, F. (2021). Estimated biomass loss caused by the Vaia windthrow in Northern Italy: Evaluation of active and passive remote sensing options. Remote Sensing, 13(23), 4924.

Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O. P., Viiri, H., ... & Peltola, H. (2020). Climate change induces multiple risks to boreal forests and forestry in Finland: A literature review. Global change biology, 26(8), 4178-4196.

Wang, L., Long, F., Liao, W., & Liu, H. (2020). Prediction of anaerobic digestion performance and identification of critical operational parameters using machine learning algorithms. Bioresource technology, 298, 122495.

Wohlgemuth, T., Schwitter, R., Bebi, P., Sutter, F., & Brang, P. (2017). Post-windthrow management in protection forests of the Swiss Alps. European Journal of Forest Research, 136, 1029-1040.

Zeller, M. A., Arendsee, Z. W., Smith, G. J., & Anderson, T. K. (2023). classLog: Logistic regression for the classification of genetic sequences. Frontiers in Virology, 3, 1215012.

# Development of Low-Cost IR Forest Scanner

**Burak Türkay*[1], Abdurrahim Aydın[2]**

[1]Düzce University, Institute of Science, 81620 Düzce, Türkiye
[2]Düzce University, Faculty of Forestry, Konuralp Campus, 81620 Düzce, Türkiye
*burak.turkay@hotmail.com

**Abstract**

Forests serve a wide range of critical ecological functions (generate oxygen, etc.) and provide significant resources, including the production of eco-friendly goods (wood products, food etc), carbon cycling, habitat, and carbon dioxide absorption. Regrettably, the capacity of forests to perform these functions, as well as their productivity and health, are jeopardized owing to insects and disease, drought, forest fires, trade, land use and climate change, and forest area loss. Since forests, an indispensable resource, are constantly under threat and human pressure, the forestry sector must transition to the smart, technological forestry. In technological forestry, measuring, mapping and assessing forests using infrared (IR) distance meters is significant. By measuring the whole forest using IR distance meters, a digital twin of the forest may be produced on the computer, which allows high-accuracy retrieval of forest information (diameter, height). When it comes to high-accuracy information, low-cost devices can be equivalent to much costlier ones. Thus, low-cost various technologies, can be used to attain the desired information. In this research, an IR scanner was developed to scan forests at low-cost and serve as a prototype for sophisticated technologies. Sharp-GP2Y0A710K0F sensor, SG90 servo motor, and Atmega328p microcontroller were utilized, together with the necessary electronic and software improvements like filtering for voltage oscillates and noise, and multi-reading averaging for deviations. Scanner rotates 180 degrees horizontally and 150 degrees vertically, and the distance measured by the sensor is saved alongside the pertinent degrees with each rotation. As a result, a scanner prototype has been developed that generates a dataset from which a digital twin may be constructed, therefore enhancing and easing forestry analysis.

***Keywords:*** *3D Scanner, Forest scanning, IR measurement, remote measurement*

## 1. Introduction

Forests serve a wide range of critical ecological functions (Ramsfield et al., 2016) (generate oxygen, etc.) and provide significant resources, including the production of ecofriendly goods (wood products, food, etc), carbon cycling, habitat, and carbon dioxide absorption (Isabel et al., 2020). Regrettably, the capacity of forests to perform these functions, as well as their productivity and health, are jeopardized owing to insects and disease, drought, forest fires, trade, land use and climate change, and forest area loss (Pautasso et al., 2015; Millar and Stephenson, 2015; Isabel et al., 2020). Since forests, an indispensable resource, are constantly under threat and human pressure, the forestry sector must transition to the technological forestry. In technological forestry, scanning, mapping and assessing forests using IR distance meters is significant. By scanning the whole forest using IR distance meters, a digital twin of the forest may be produced on the computer, which allows high-accuracy retrieval of forest information (diameter, height). A variety of technologies at diverse price ranges can facilitate this process, encompassing backpack, aerial, terrestrial, and handheld scanners (Figure 1). Inexpensive handheld laser scanning technology to deliver very accurate data equivalent to existing studies that employed far higher priced commercial technologies (Shaw, 2022), consequently, even low-cost technologies can be used to attain the desired information.

Figure 1. Handheld (a), backpack (b) and terrestrial (c) scanners (Shaw, 2022)

Given the array of available technologies, a crucial step in their selection is the evaluation of their relative merits for a given purpose. To this end, a study compared the performance of inexpensive ones. In this study, which concentrated on diameter measurement and tree detection, the terrestrial laser scanner delivered the most accurate data among the iPad Pro 2020, multi camera prototype, and GeoSlam Horizon (Mokroš et al., 2021). Aside from the hardware platforms, the approaches and algorithms utilized also have a significant influence on accuracy. For instance, the single scanning technique of the terrestrial scanner has the lowest accuracy, whereas its multi scan technique and backpack scanner have great accuracy for tree diameter/height estimation. In the context of sloped terrain, backpack scanner may yield erroneous outcomes. (Ko et al., 2022).

Various approaches and techniques have been searched, tried and compared since the past to illustrate the success of laser scanning technologies or to analyze/improve that technologies (Hyyppä et al., 2004; Kuželka et al., 2022). Laser scanning technology coupled with simultaneous localization and mapping algorithm, for example, gives fruitful remedy for the forest inventory (Chen et al., 2019). In a study on employing cameras to acquire forest data (diameter, position), the forest area was photographed (with utilizing various routes and camera settings) and techniques were compared to one another. As a result of the comparison of image based (camera-based, photographic) technique with personal and terrestrial laser scanning techniques, it has been reported that laser techniques are more successful in terms of tree feature estimation accuracy (Liang et al., 2015). When laser scanning techniques (multi/single-scan terrestrial laser scanning and handheld laser scanning) for estimating forest features are compared, it is revealed that handheld laser scanning is speedier than multi-scan terrestrial laser scanning and gives better results for the diameter and tree detection (Bauwens et al., 2016). Comparing diverse laser scanning techniques (above/under canopy unmanned aircraft scanning systems and handheld/backpack scanners) in the boreal forest revealed that ground based scanning systems may be utilized to quantify diameter, and hand-held scanners can be used to measure tree height (Hyyppä et al., 2020). Although scanning devices are very convenient for rapid and precise measurement of forest parameters such as diameter and height, there is a critical need to reduce their prices and sizes while simplifying their structures. This will facilitate broader accessibility to students for hands-on learning and experimentation, as well as to a wider audience for comprehension and advancement.

Another technology called IR sensors are of great importance in the field of forest scanning, as they provide a reliable and cheap method for measuring a range of forest attributes (diameter, height). These sensors operate by emitting infrared light and detecting its reflection from objects, thereby enabling the precise measurement of distances. In forestry applications (management, measurement), IR sensors are particularly useful for calculating tree diameters and heights, as they can accurately assess distances and dimensions even in dense forest environments. Furthermore, their low power consumption and relatively low cost make them an ideal choice for integration into portable and affordable scanning devices. The utilisation of IR sensors in the forest scanner ensures the collection of reliable data, while maintaining simplicity and cost-effectiveness. This further enhances the accessibility of the scanner to educational/training and experimental purposes.

In this study, a prototype-level IR forest scanner was developed with the objective of keeping the budget as low as possible while selecting simple materials. The system's low cost, simple design, and easily replaceable parts have made it accessible to a wide range of users, including students. This accessibility allows users to work on the system in various ways, including mechanically, electronically, or software-wise, without fear of damaging it. The system's straightforward design and ease of use make it an ideal platform for testing and studying, allowing users to gain a deeper understanding of its capabilities and technology. Sharp-GP2Y0A710K0F sensor, SG90 servo motor, and Atmega328p microcontroller were utilized, together with the necessary electronic and software improvements like filtering for voltage oscillates and noise, and multi-reading averaging for deviations. Scanner rotates 180 degrees horizontally and 150 degrees vertically, and the distance measured by the sensor is saved alongside the pertinent degrees with each rotation. As a result, a scanner prototype has been developed that generates a dataset from which a digital twin of forest may be constructed, therefore enhancing and easing forestry analysis.

## 2. Material and Methods

In this research, an IR scanner was developed to scan forests at low-cost and serve as a prototype for sophisticated technologies. A number of materials and components were employed, in conjunction with the requisite electronic and software enhancements, as detailed in the following sections. Section 2.1 delineated the principal components, while Section 2.2 elucidated the methodology.

### 2.1. Materials

The project primarily employed the Sharp-GP2Y0A710K0F sensor, SG90 servo motor, and Atmega328p microcontroller. Moreover, a variety of consumable components were utilized, including, crystal, resistors, capacitors, regulators, potentiometer, buttons, etc.

#### 2.1.1. Sharp GP2Y0A710K0F

This device is a distance measuring sensor unit which comprises an integrated combination of a position sensitive detector, an infrared emitting diode and a signal processing circuit. The GP2Y0A710K0F gives a voltage related to distance. The characteristics (Table 1) and image (figure 2) of the component are delineated below (Datasheet1, 2024).

Table 1. The characteristics of the component (Datasheet1, 2024).

| | | | |
|---|---|---|---|
| Type: | long distance | Package size: | 58×17.6×22.5 mm |
| Distance measuring range: | 100 to 550 cm | Supply voltage: | 4.5 to 5.5 V |
| Analog output type: | Yes | Consumption current: | typ. 30 mA |

Figure 2. Sharp GP2Y0A710K0F (Datasheet1, 2024)

#### 2.1.2. SG90 Servo Motor

The device is characterized by its minimal dimensions, lightweight construction, and substantial power output. The servo mechanism exhibits a rotary motion of approximately 180 degrees. The characteristics (table 2) and image (figure 3) of the component are delineated below (Datasheet2, 2024).

Table 2. The characteristics of the component (Datasheet2, 2024)

| | | | |
|---|---|---|---|
| Weight: | 9 g | Operating voltage: | 4.8 V (~5V) |
| Dimension: | 22.2 x 11.8 x 31 mm approx. | Dead band width: | 10 µs |
| Stall torque: | 1.8 kg·cm | Temperature range: | 0 ºC – 55 ºC |
| Operating speed: | 0.1 s/60 degree | | |

Figure 3. SG90 servo motor (Datasheet2, 2024)

#### 2.1.3. Atmega328p Microcontroller

ATmega328P is an 8 bit low power CMOS micro-controller based on the AVR enhanced RISC architecture. The characteristics (table 3) and image (figure 4) of the component are delineated below (Datasheet3, 2024).

Table 3. The characteristics of the component (Datasheet3, 2024)

| | | | |
|---|---|---|---|
| Pin Count: | 28/32 | TWI ($I^2C$): | 1 |
| Flash (Bytes): | 32K | USART: | 1 |
| SRAM (Bytes): | 2K | ADC: | 10-bit 15kSPS |
| EEPROM (Bytes): | 1K | ADC Channels: | 8 |
| Interrupt Vector Size (instruction word/vector): | 1/1/2 | 8-bit Timer/Counters: | 2 |
| General Purpose I/O Lines: | 23 | 16-bit Timer/Counters: | 1 |
| SPI: | 2 | | |

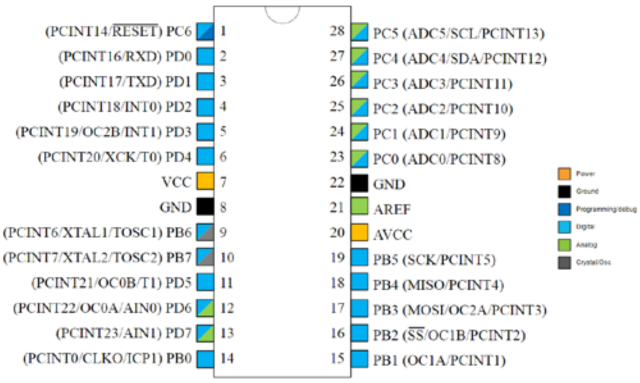



Figure 4. Atmega328p microcontroller (Datasheet3, 2024)

## 2.2. Methodology

In the study, the Sharp GP2Y0A710K0F laser distance sensor was utilized. The sensor is capable of measuring distances up to a maximum of 5.5 meters. It should be noted that the Sharp laser distance sensor is susceptible to potential electrical surges. To circumvent this issue, a study was conducted to develop a filtration system, wherein a 10uF (microfarad) 16V (volt) capacitor was utilized. On top of that, there were discrepancies observed between the readings taken by the sensor for the same point. In order to reduce these discrepancies, twenty-five readings were taken for each point to be measured, and the average of these readings was taken as the net result for that point. The accuracy of the net result was then tested with a Leica laser meter. The point whose distance was measured by the sensor was measured again with the Leica laser meter from the same angle and location, and the results were evaluated (Figure 5).


Figure 5. Representative test photo with Leica laser meter (left) and sensor measurement results in meters (right)

In order to perform a 3D scan, it is necessary to move the Sharp laser distance sensor in both the horizontal and vertical axes (figure 6). Two SG90 servo motors were employed for this purpose. The simultaneous operation of two motors can result in the drawing of excess current. To prevent excessive current flow through the microcontroller, the voltage input of the servo motors is taken from an external source. Beside this, an investigation has been conducted to ascertain the optimal methodology for operating the motor in a smooth and stable manner. The motor is provided with a 15 ms (milliseconds) waiting period to allow for the completion of the current action and the initiation of the next step. It was observed that times less than 15 ms or more than 15 ms resulted in a disruption to the stability of the motor operation. Servo motors are employed to scan 180 degrees along the horizontal axis and 150 degrees along the vertical axis. At each stage of the scan, angular position readings are obtained from the motors, enabling the angles of the measured point on the horizontal and vertical axes to be determined. This process allows the distance of each measured point from the scanner and the angular position of each measured point in the horizontal and vertical axes relative to the scanner to be calculated. The distance measured by the sensor is saved with every rotation, along with the angular degrees that correspond to that measurement.

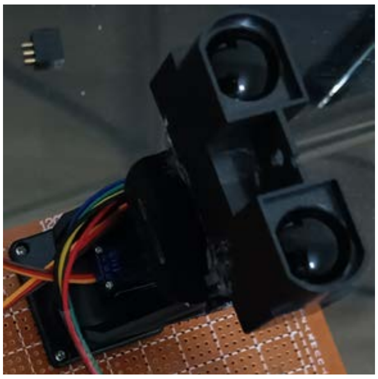


Figure 6. Three-dimensional scanning platform

The system was controlled by an Atmega328p 8-bit, 20 MHz microcontroller. This Atmega328p was supplied with a voltage of 5 volts. A 16 MHz crystal and two 22 pF (picofarad) 63 V capacitors were employed for the operation of the Atmega328p and frequency settings. A reset button was constructed for the microcontroller, incorporating a 10K ohm pull-up resistor. The reset button is designed to initiate a system restart in the event of an adverse situation. An LCD display was employed to illustrate the progression of the system and any adverse situation that may arise. The LCD screen comprises two rows and 16 columns. A 10 kiloohm potentiometer was employed for the purpose of adjusting the screen's contrast. In addition to these, the potential for wireless communication, specifically Bluetooth and LoRa, was explored as a means of transferring the collected and calculated data to a computer. However, these wireless communication techniques did not permit simultaneous transfer (to the computer software) of the calculated data at the same speed as the measurement process. For this reason, an SD card module was utilized to store the calculated data. The SD card module operated using SPI (Serial Peripheral Interface) communication. To provide the necessary voltage to power everything from the SD card module to the entire system, two 5-volt regulators were employed. Given that regulators have a tendency to overheat, it was deemed appropriate to share the entire electrical load of the system between two regulators. Also, aluminium coolers were utilized to mitigate the potential for regulator heating. In addition to this, two 10uF 16-volt capacitors were incorporated to prevent noise and voltage drop in the regulators (figure 7).

Figure 7. Main circuit board

As a consequence of these methodologies, the development of a prototype IR scanner device has been accomplished (figure 8). This device has been engineered to scan forests in three dimensions, to be economically viable, to possess a straightforward and comprehensible structural configuration and to be user-friendly. Furthermore, it is intended that this prototype will be suitable for use in both educational/training and research contexts and will provide the foundation for the development of advanced, next-generation devices.

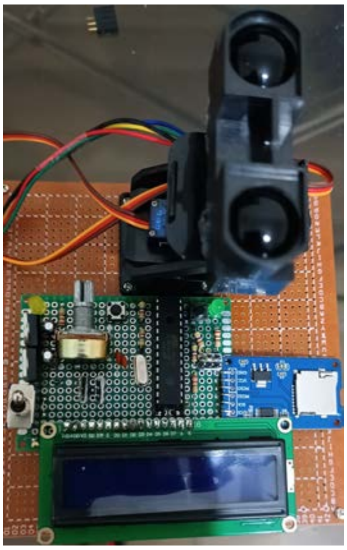


Figure 8. Developed prototype IR scanner

## 3. Results and Discussion

In this research project, we developed an infrared scanner with the objective of providing a low-cost solution for forest scanning, serve as a training and experimental tool, while concurrently establishing the technical foundations for the development of more sophisticated scanning technologies. This research employed the use of a Sharp-GP2Y0A710K0F sensor, SG90 servo motors, and an Atmega328p microcontroller, in conjunction with the requisite electronic and software enhancements, including filtering for voltage oscillations and noise, and multi-reading averaging for deviations.

In the context of prototyping and testing, it was observed that low-cost and short-range laser distance sensors, such as the GP2Y0A710K0F, can also be employed for this purpose. Furthermore, the laser distance sensor is susceptible to interference from electrical fluctuations. In order to mitigate the impact of electrical noise and fluctuations, a 10 µF 16 V capacitor was identified as an effective solution for this study. Even with that solution, there were deviation in the recorded measurements. To reduce the deviation in the measurements, it was determined that it was appropriate to conduct 25 measurements and take the average of the measurement results. With this methodology, the mean absolute error for measurements taken at distances shorter than 2.5 m was 5.4 cm, while the mean absolute error for measurements taken at distances longer than 2.5 m was 16 cm (Figure 9). However, there are devices, such as the Leica RTC360, that are capable of achieving millimetre-level accuracy and have a scan range of 130 metres (Ko et al., 2022).

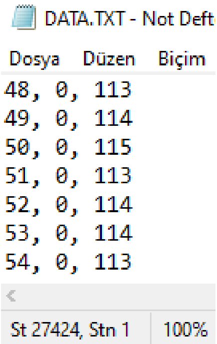

DATA.TXT - Not Deft
Dosya Düzen Biçim
48, 0, 113
49, 0, 114
50, 0, 115
51, 0, 113
52, 0, 114
53, 0, 114
54, 0, 113
St 27424, Stn 1 100%

Figure 9. Representative measurements (angle information’s, distance)

The SG90 servo motor was employed to facilitate the movement of the sensor during the course of the measurements. With the SG90, the system is capable of scanning 180 degrees in a horizontal direction and 150 degrees in a vertical direction within a range of 5.5 meters. Nevertheless, there are devices (ZEB-REVO-RT) with technical specifications that indicate a maximum range of 15 meters outdoors and a field of view angle of 270° by 360° (Chen et al., 2019). In the context of the study, it was deemed appropriate to ascertain the angles of the measured point relative to the scanner in the horizontal and vertical axes by means of angular position readings obtained from the servo motor. A further crucial aspect of servo motors is their voltage supply. It was observed that when two servo motors operate in conjunction, an excessive current can be drawn, which may result in overheating. It was therefore deemed appropriate to source the voltage input for the servo motors from an external source. The motors were operated in a manner that was as smooth and stable as possible. For this, it was determined that a 15 ms waiting period between motor steps was optimal. This resulted in a scan time of 8:52 minutes. In conjunction with the 360-degree scan (a secondary scan is conducted for the incomplete 180 degrees) and the setting up process (only fastening on a level surface or on a tripod in a levelled position), the entire fieldwork undertaking requires approximately 20 minutes within the area in range. In a study employing a variety of devices and techniques (FARO Focus 3D 120, ZEB1), the total fieldwork (setting up and scan) time ranged from a minimum of 10 minutes to a maximum of 1 hour and 15 minutes (Bauwens et al., 2016). With backpack and handheld scanners, there are cases where the data acquisition time is about 10 minutes (Hyyppä et al., 2020). It was observed that the SG90 servo motor could be utilized for the prototype, but that a more sensitive, stable, and wide-angle motor would be required.

Atmega328p 8-bit, 20 MHz microcontroller was found adequate for the purpose of controlling the scanner. However, it was determined that the integration of a reset button on the microcontroller and an LCD screen for workflow monitoring would prove beneficial in addressing potential issues. A 10K ohm potentiometer was identified as an appropriate component for adjusting the contrast of the LCD screen at the different environment. On the other hand, studies were conducted to evaluate the feasibility of wireless communication for data transfer from the microcontroller to a computer. The investigated communication protocols included Bluetooth and LoRa. It was discovered that both Bluetooth and LoRa are unable to facilitate the transfer of calculated data to a computer at the identical speed and simultaneously with the measurement process. As an alternative solution, the use of a SD card module was identified as a viable option. From the SD card module to the entirety of the other components, it is necessary that all of the aforementioned components be supplied with the requisite voltage. In order to provide the requisite voltage, it may be necessary to bring the power supply to the necessary voltage level using a regulator. Given that regulators have a tendency to overheat, it was deemed appropriate to share the entire electrical load of the system between two regulators. Furthermore, the use of aluminium heat sinks for the purpose of regulating temperature and maintaining optimal functionality of the regulators was observed to be an effective solution. In addition to this, two 10uF 16-volt capacitors were found to be sufficient for this study in order to prevent noise and voltage drop in the regulators.

## 4. Conclusion and Suggestions

The objective of the present study was the development of a prototype-level IR forest scanner with the aim of keeping the budgetary constraints to a minimum while selecting straightforward and uncomplicated materials. The system's affordability, simple configuration, and readily replaceable components facilitate accessibility for a diverse user base, including academic researchers and students. This accessibility enables users to engage with the system through diverse avenues, including mechanical, electronic, and software-related modifications, without concern of compromising the system's integrity. The system's straightforward design and user-friendly interface make it an optimal platform for experimenting and research, allowing users to gain a comprehensive understanding of its functional capabilities and technological underpinnings. With regard to the technological infrastructure, Sharp-GP2Y0A710K0F sensor, SG90 servo motor, and Atmega328p microcontroller were utilized, together with the necessary electronic and software improvements like filtering for voltage oscillates and noise, and multi-reading averaging for deviations. These elements may be employed for the purposes of prototyping, learning, or testing; however, for more advanced work, it is recommended that higher-level elements be utilized.

A basic-level scanner has been developed that generates a dataset from which a digital twin of forest may be constructed. This has two main benefits. First, it enhances (accuracy, etc.) forestry analysis in general. Second, it makes such analysis easier (in terms of the level of exertion required, etc.), which should increase the speed at which results can be obtained. Furthermore, the use of scanners, such as IR, etc., remote sensing methods, and other technological possibilities in forestry allows for more accurate, precise, and free of human error evaluation and planning of the future of forests. It is therefore necessary and highly recommended to increase the use of such scanners, remote sensing methods, and other technological possibilities in forestry, as well as to teach them. Such studies should be multiplied both for training and for the development and accessibility of technology.

## References

Bauwens, S., Bartholomeus, H., Calders, K., Lejeune, P. 2016. Forest inventory with terrestrial LiDAR: A comparison of static and hand-held mobile laser scanning. Forests. 7(6): 127.

Chen, S., Liu, H., Feng, Z., Shen, C., Chen, P. 2019. Applicability of personal laser scanning in forestry inventory. PLoS One. 14(2): e0211392.

Datasheet1. 2024. GP2Y0A710K0F Datasheet (PDF) - Sharp Corporation. Accessed: 14.08.2024. <https://pdf1.alldatasheet.com/datasheet-pdf/view/190301/SHARP/GP2Y0A710K0F.html>.

Datasheet2. 2024. SG90 Datasheet (PDF) - List of Unclassifed Manufacturers. Accessed: 14.08.2024. <https://pdf1.alldatasheet.com/datasheet-pdf/view/1572383/ETC/SG90.html>.

Datasheet3. 2024. ATMEGA328P-PU Datasheet (PDF) - ATMEL Corporation. Accessed: 14.08.2024. <https://pdf1.alldatasheet.com/datasheet-pdf/view/1425635/ATMEL/ATMEGA328P-PU.html>.

Hyyppä, E., Yu, X., Kaartinen, H., Hakala, T., Kukko, A., Vastaranta, M., Hyyppä, J. 2020. Comparison of backpack, handheld, under-canopy UAV, and above-canopy UAV laser scanning for field reference data collection in boreal forests. Remote Sensing. 12(20): 3327.

Hyyppä, J., Hyyppä, H., Litkey, P., Yu, X., Haggrén, H., Rönnholm, P., Pyysalo, U., Pitkänen, J., Maltamo, M. 2004. Algorithms and methods of airborne laser-scanning for forest measurements. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. 36(8): 82-89.

Isabel, N., Holliday, J. A., Aitken, S. N. 2020. Forest genomics: Advancing climate adaptation, forest health, productivity, and conservation. Evolutionary Applications. 13(1): 3-10.

Ko, C., Lee, J., Kim, D., Kang, J. 2022. The Application of Terrestrial Light Detection and Ranging to Forest Resource Inventories for Timber Yield and Carbon Sink Estimation. Forests. 13(12): 2087.

Kuželka, K., Marušák, R., Surový, P. 2022. Inventory of close-to-nature forest stands using terrestrial mobile laser scanning. International Journal of Applied Earth Observation and Geoinformation. 115: 103104.

Liang, X., Wang, Y., Jaakkola, A., Kukko, A., Kaartinen, H., Hyyppä, J., Honkavaara, E., Liu, J. 2015. Forest data collection using terrestrial image-based point clouds from a handheld camera compared to terrestrial and personal laser scanning. IEEE transactions on geoscience and remote sensing. 53(9): 5117-5132.

Millar, C. I., Stephenson, N. L. 2015. Temperate forest health in an era of emerging megadisturbance. Science. 349(6250): 823-826.

Mokroš, M., Mikita, T., Singh, A., Tomaštík, J., Chudá, J., Wężyk, P., Kuželka, K., Surový, P., Klimánek, M., Zięba-Kulawik, K., Bobrowski, R., Liang, X. 2021. Novel low-cost mobile mapping systems for forest inventories as terrestrial laser scanning alternatives. International Journal of Applied Earth Observation and Geoinformation. 104: 102512.

Pautasso, M., Schlegel, M., Holdenrieder, O. 2015. Forest health in a changing world. Microbial Ecology. 69(4): 826-842.

Ramsfield, T. D., Bentz, B. J., Faccoli, M., Jactel, H., Brockerhoff, E. G. 2016. Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. Forestry. 89(3): 245-252.

Shaw, D. G. 2022. Developing a low-cost Handheld Terrestrial LiDAR Scanner for sub-canopy woodland mapping: The cost of sub-canopy tree mapping and its occlusion, Master Thesis, Bangor University, Bangor, United Kingdom. 147 p.

# Performance Analysis in Timber Loading Operations with A Tractor-Mounted Single-Gear Front Loader

**Saliha Ünver[1*], H. Hulusi Acar[2]**

[1] Karadeniz Technical University, Faculty of Forestry, Trabzon, Türkiye
[2] Istanbul Yeni Yüzyıl University, Health Science Institute, Istanbul, Türkiye
*salihaunver@ktu.edu.tr

## Abstract

One of the most important stages in the efficiency of harvesting operations is the proper planning of loading operations that provide the link between primary and secondary transportation. Modified tractors are the most used in loading operations due to the high cost of advanced mechanization tools. The performance of the loading operation with a tractor-mounted single-gear front was determined in spruce (*Picea orientalis* L. Link) forests in northeastern Türkiye. In the study, the diameter and length of the loaded logs were measured, the quantities loaded each time were determined, and their volumes were calculated. The average diameter and length of the loaded logs are 34 cm and 4 m, respectively. The performance of the loading activity was determined by time measurements taken during the stages of placing the logs in the bucket (f1), transferring them to the truck (f2), loading them (f3), and returning them to the logs (f4). The productivity of the loading activity was calculated from the volume and time measurements. The relationships between the volume and number of logs loaded at each time and work performance were statistically evaluated.

***Keywords:*** *Forest operations, biomass harvesting, time and motion study, work productivity*

## 1. Introduction

The demand for wood-based materials remains high due to various advantages such as strength, elasticity, low sound and thermal conductivity, renewability, aesthetics, and low specific weight although many materials can be used as alternatives in the industry. Approximately 90% of the forest areas covering 29.4% of Türkiye's surface area belong to the state and are managed by the General Directorate of Forestry (GDF). The number of industrial logs targeted to be produced by the GDF for 2024 is approximately 25 million 600 thousand $m^3$ (GDF, 2024). However, interventions such as improper land use, unplanned settlement, excessive use, illegal logging, and opening create significant pressure on forests. In addition, many trees and forest areas have been greatly damaged due to disasters such as forest fires, which have increased considerably in recent years. For these reasons, it is important to make wood harvest plans by considering the needs of society and sustainable forest management (Ünver et al., 2024).

The fact that forests are far from settlements makes it difficult for consumers to obtain the produced logs directly from the forests. Therefore, the wood that will meet the demands must wait in the forest and be delivered to the consumer as soon as possible without being damaged. The process involves collecting the timber from the side of the road, loading it onto trucks, and transporting it to outlets and final destinations. The wood raw material production process happens in three main stages: felling (cutting, branch removal, bark removal if necessary, and sorting), primary transportation, and secondary transportation (Figure 1).

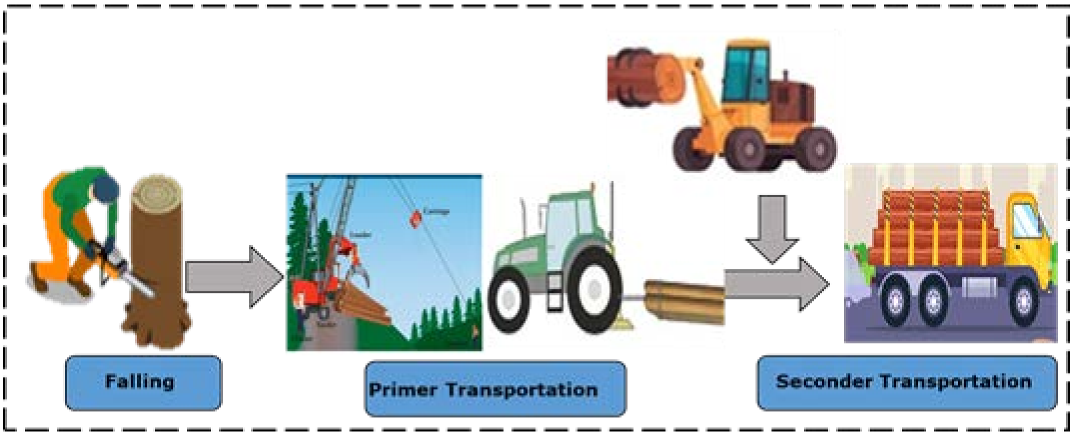


Figure 1. Forest harvesting process

One of the most important tasks in forest harvest healthily and efficiently is loading activities that establish the link between primary and secondary transport. Log loading activity is the beginning of seconder transportation, which involves taking the wood from its location and placing it on a transport vehicle (Minette et al., 2014). The efficiency and cost of forest transportation activities are directly related to loading and unloading activities (Arcego et al., 2019). Costa et al. (2003) determined that delays in secondary transportation operations largely depend on the performance of loading and unloading activities. A high performance in loading operations can only be achieved with proper time management and good work planning. Akay et al. (2020) emphasized that the efficiency of loading operations can be achieved by good planning and harmonious execution of the sub-stages of these operations. Thousands of truck trips carry out the transport of millions of logs produced annually in Türkiye to warehouses. This shows the importance of performing loading operations with good performance, which affects both the efficiency and cost of secondary transport. Poor performance in loading operations can cause wood to remain in the forest for a long time and be exposed to significant economic and ecological damage. While various quality and value losses can occur on logs from a financial perspective (Ünver-Okan, 2020), they can also cause forests to become susceptible to insect exposure from an ecological perspective by becoming insect nests.

Small-sized woods such as industrial and firewood can be loaded onto vehicles by manpower. At the same time, high-capacity loading loaders are needed if the size, quantity, and volume of logs are large. The logs are loaded onto vehicles such as trucks or lorries by manpower, wire winch or grapple loaders, mobile rotary cranes, hydraulic grapple loaders, excavators, granabs, or modified tractors (Ghaffariyan, 2021; Gülci, 2014). In Türkiye, an alternative loading system consisting of a portable hand winch and polyethylene chutes has been developed as an alternative (Acar, 2016). Modified tractors are generally preferred for several reasons such as largely carried out by low-income forest villagers, the high cost of advanced mechanization, and the need for skilled workers/operators.

The main factors affecting the performance of log loading operations are; machine type, loading season (summer/winter), ramp status (available/not available), loaded distance, vehicle speed, wood size and quantity, volume and number of loaded logs in each cycle, loading height and operator skill/experience (Sporcic et al., 2023; Hartsch et al., 2022; Louis et al., 2022; Ghaffarian, 2021; Manner, 2021; Hildt et al., 2020; Parajuli et al., 2020; Strandgard and Mitchell, 2019; Arcego et al., 2019; Malinen at al., 2016; Mederski et al., 2016; Strandgard et al., 2015; Minette et al., 2014; Dos Santos et al., 2013; Stankić et al. 2012). In forest stacking areas where loading ramps are not available and in forests where manual loading techniques are used (Gülci et al., 2018), there may be a significant increase in both costs and time spent on the loading operations.

The most widely used method for estimating the performance of forest operations is time study methods. Time study is defined as studies to increase the efficiency of the materials, tools, and equipment used (time measurement, work classification, and data analysis) (Mirkala and Naghdi, 2017; Duran et al., 2015; Puvanasvaran et al., 2013). Therefore, time studies are highly effective in improving operations and reducing operating costs (Strandgard and Mitchell, 2015). These studies provide important contributions to forest harvesting plans, budget preparation, comparison of different equipment or methods, and the completion of the work plan on time. Good performance in loading operations is possible by reducing the total work cycle time, increasing active working time, and reducing lost time (Machado et al., 2009).

This study aimed to determine the performance of the loading operations of logs of different lengths and distances with a tractor-mounted single-tooth front end in mixed forests of oriental spruce (*Picea orientalis* L. Link) and beech (*Fagus orientalis* Lipsky.) in the northeast of Türkiye.

## 2. Material and Methods

The study was conducted in oriental spruce (*Picea orientalis* L. (Link)) and beech (*Fagus orientalis* Lipsky.) mixed forests in the Doğankent region of Giresun in the northeast of Türkiye (49° 23' 15" N and 45° 05' 67.5" W) (Figure 2). The average elevation, area, and slope are 1800 m, 28.4 $m^2$, and 43%, respectively. The average annual temperature and rainfall are recorded at the Giresun weather station at 14°C and 1660 mm, respectively. The hottest and coldest months are June (36.2 °C) and February (-9.8 °C). The months with the highest rainfall are April-May and October-December (Turkish State Meteorological Service, 2024).

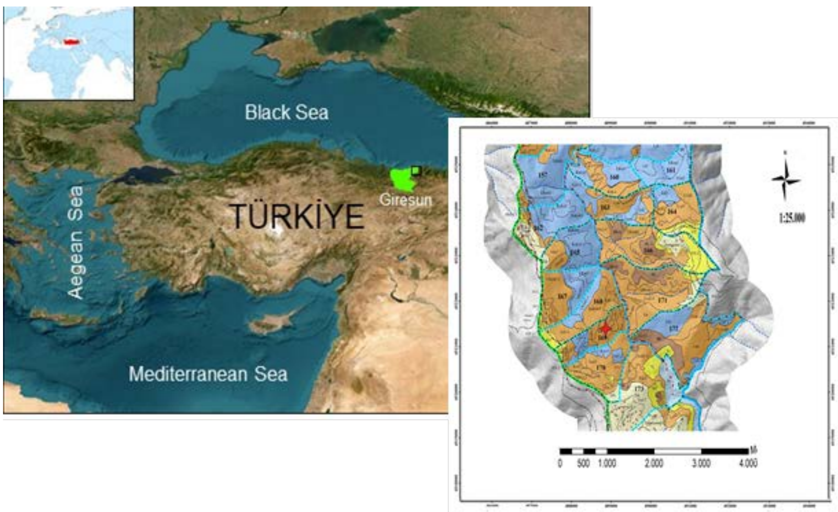



Figure 2. Study area

## 2.1. Loading Operations

The study examined loading operations with a tractor mounted on a single-tooth loader. The loading operations were carried out in July 2024 with an operator with more than 5 years of experience and three forest workers. While the operator operated the loader, the workers helped guide the operator and secure the timber on the truck. The number of logs loaded at each cycle (n/cycle), diameter (d-cm), and length (l-m) were measured and the volume of the logs (V-m3) was calculated with the Huber formula (Equation 1) (Castellanos et al., 2007).

$$V = \frac{\pi}{4}\, d^2\, l \qquad (1)$$

## 2.2. Performance Analysis

The main principle of time study is to divide the work into small work elements. Work has been divided into basic tasks and time categories according to typical functions and tasks of forest contractors (Cataldo et al., 2022; Proto et al., 2020). In the study, the flow slices of the loading operations were determined to reveal the efficiency of the loading operations, and the realization times of each were measured. Before the time measurements, the loading of three logs was observed and four main flow slices for the loading operation were determined (Figure 3).

F1: Travel empty

F2: Holding

F3: Travel loaded

F4: Loading and placing on the truck

Figure 3. Workflow stages

F1- Travel Empty: Starts with the loader moving to the side of the logs empty and ends when it is ready to pick up the logs

F2- Holding: Starts with the loader's grapple moves and reaches the log and ends with the log holding and moving

F3- Travel Loaded: Starts with the loader moving with the load and ends with the loader moving to the side of the truck and stopping

F4- Loading and placing on the lorry: Starts with the loader moving the grapple towards the lorry bed (forward-up) and ends with the loader placing the log on the lorry

The realization times of each flow stage were measured using a stopwatch with snap-back (repeated) time study techniques. The time study monitored an average worker completing a task at a normal pace (Sable, 2014). In addition, operational lost time due to disruptions caused by workers, loaders or work during the loading period was also recorded. During the measurements, communication between the operator, the loading workers, and the observer was provided by a communication network established with Cobra handheld radios. After the measurements, the average travel time and the total working time were calculated. The gross efficiency of the loading operation ($P_g$-m$^3$/hr) was calculated by Equation (2) and the net efficiency ($P_e$-m$^3$/hr) without considering the lost time was calculated by Equation (3) (Tyulenev et al., 2017).

$$P_g = \frac{V}{t_t + t_k} \tag{2}$$

Here, V is the average volume of product transported in a cycle (m$^3$); $t_t$ is the total time (hr/cycle); $t_k$ is the loss time (hr/cycle).

$$P_e = \frac{V}{t_t} \tag{3}$$

**2.3. Statistical Analysis**

Statistical analyses were carried out in the IBM SPSS 23.0 software environment. In the scope of the study, descriptive statistics of the measured and calculated data were determined. The relationship between the volume of logs in a cycle and the total cycle time was evaluated by Pearson analysis. Linear regression analysis was used to determine the effects of the log volume in each cycle on the total cycle time.

**3. Results and Discussion**

The performance of loading logs onto trucks from distances of 25.4 m to 51.1 m was evaluated in this study. During the loading process, 27.97 m$^3$ of logs were loaded onto the trucks from an average distance of 38.25 m in about two hours of effective time. An average of 1.4 logs were loaded per cycle and the average diameter, length, and volume were 35.86 cm, 4.06 m, and 0.59 m$^3$/cycle, respectively. The descriptive statistics of the log volume loaded in each cycle, the duration of the workflow segments, gross productivity, net productivity, and net total time parameters are shown in Table 1.

Tablo 1. The descriptive statistics of operational parameters

| | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| Volume per cycle (sec) | ,113982 | 2,08182 | ,59505 | ,44411 |
| Travel empty (sec) | 18,00 | 87,00 | 40,5681 | 21,68862 |
| Holding (sec) | 4,00 | 86,00 | 23,7660 | 17,86021 |
| Travel loaded (sec) | 12,00 | 151,00 | 51,9064 | 34,41127 |
| Loading to truck (sec) | 3,80 | 201,00 | 33,8553 | 44,87165 |
| Net total time per cycle (sec) | 54,00 | 478,80 | 150,0957 | 108,52635 |
| Net productivity per cycle (m$^3$/h) | 4,05069 | 66,35356 | 16,65082 | 14,06169 |
| Gross productivity (m$^3$/h) | 3,64198 | 66,35356 | 15,47913 | 12,48419 |

As seen in Table 3, the average effective productivity was calculated as 16.65 $m^3$/h. In the literature the productivity for machine loading operations was found to be 34.27 $m^3$/h (Akay et al., 2020) and 48.67 $m^3$/h (Karaman, 1991). The difference between the results of this study and the literature may be because the logs were loaded directly next to the lorries in other studies. In contrast, the logs were brought in and loaded at an average distance of 38.25 m in this study. The proportional distributions of the net times of the four workflow segments examined in the loading time measurements are shown in Figure 4.

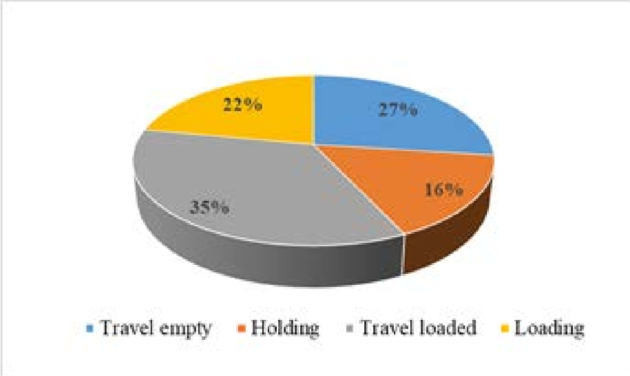



Figure 4. Proportional distribution of work stages

As seen in Figure 4, the most time-consuming stage is the travel-loaded stage (35%), similar to Akay et al. (2020), and the least time-consuming stage is the holding stage (16%). The travel loaded stage takes too much time due to the average distance of 35.38 m between the logs and the truck. Approximately 13% of the total time was lost during loading operations. The proportional distribution of personal, operational, and mechanical time lost during the study was determined (Figure 5).

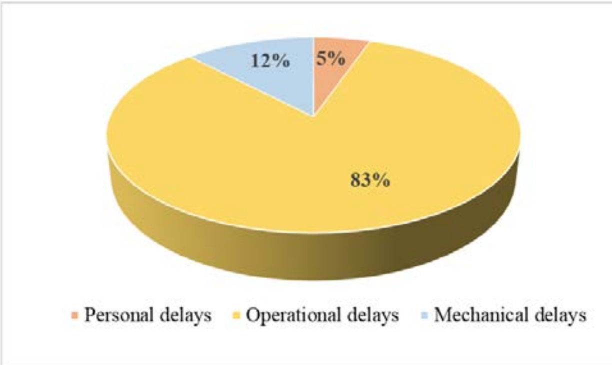



Figure 5. Proportional distribution of lost times

As seen in Figure 5, most of the lost time in loading operations is operational lost time (82.6%) due to errors in the holding and loading stages. The least lost time occurred in the personal lost time (5.3%) stages caused by workers. The mechanical lost time (12.1%) occurred due to problems in the loading vehicle engine. The Pearson correlation test was applied to determine the relationship between volume, log length, loading distance, and net total time (Table 2).

Table 2. The Pearson correlation test results

| | | Volume | Distance | Effective total time | Lenght |
|---|---|---|---|---|---|
| Volume | Pearson Correlation | 1 | ,430** | ,568** | ,486** |
| | Sig. (2-tailed) | | ,003 | ,000 | ,001 |
| Distance | Pearson Correlation | ,430** | 1 | ,906** | ,960** |
| | Sig. (2-tailed) | ,003 | | ,000 | ,000 |
| Effective total time | Pearson Correlation | ,568** | ,906** | 1 | ,891** |
| | Sig. (2-tailed) | ,000 | ,000 | | ,000 |
| Lenght | Pearson Correlation | ,486** | ,960** | ,891** | 1 |
| | Sig. (2-tailed) | ,001 | ,000 | ,000 | |

As seen in Table 4, similar to the literature, a positive relationship was determined between log length, volume, loading distance, and effective time at a confidence level of 99% ($p<0.00$) (Kewilaa and Tehupeiory, 2015). In the regression analysis, it was determined that the travel loaded (Tl), loading (L), and holding (H) stages were effective at a confidence level of 99% ($p<0.01$) to estimate the net total time, while the stage of travel empty was not (Equation 3).

$$T_e = 13,374+1,299*Tl+1,121*L+1,319*H \qquad (R^2=0,992) \qquad (3)$$

It was found that the log volume (V) and loading distance (D) were effective in the estimation of the net total time at the 99% confidence level of ($p<0.01$) (Equation 4).

$$T_e = -128,152+7,580*D+53,518*V \qquad (R^2=0,853) \qquad (4)$$

## 4. Conclusions and Suggestions

One of the most important stages in recovering harvested logs to the economy without damage is the loading operations. In addition, the performance of these operations plays an effective role in the efficiency of forest harvesting activities. This study evaluated the performance of loading logs of different sizes from different distances with loaders commonly used in loading operations in Türkiye. It was found that the most time-consuming work stage in the loading operation was the travel loaded stage (35%) and the least time-consuming was the holding stage (16%). No personal lost time occurred within the scope of the study, and operational (89.4%) and mechanical (10.6%) lost times happened in the holding and loading stages. The average effective productivity without considering the lost times and the average gross productivity without considering them were calculated as 16.65 $m^3/h$ and 15.48 $m^3/h$, respectively. It was found the effective working time and performance of the loading activities were related to the log size, volume, and loading distance. In the regression analysis, it was determined that the work elements of travel loaded, loading, and holding were effective on the performance of the loading operation, and the work element of travel empty was ineffective. The operational lost times during loading operations are approximately 5.5 times the personal and mechanical lost times. It was observed that the operational lost times occurred largely during the handling of the logs by the loader and during the loading and placing on the truck. Reducing the lost time during loading and minimizing the possibility of work accidents largely depends on the operator's skill. Therefore, having the loader operators certified and receiving training at certain intervals will help to minimize the operational lost times.

## References

Acar, H.H. 2016. A combined loading system integrated with portable winch and polyethylene chutes for loading of timber products. Forestist 66: 329-339.

Akay, A.E., Bilici, E., Taş, I., Fındık, H.E. 2020. Productivity analysis of front-end loader in timber harvesting. European Journal of Forest Engineering 6(1): 7-13.

Turkish State Meteorological Service (TSMS), 2023. Last 35 years of climate data from Giresun meteorology station.

Arcego, H., Robert, R.C.G., Brown, R.O. 2019. Effect of log length on forestry loading and unloading. Floresta e Ambiente, 26(2): e20170269. DOI 10.1590/2179-8087.026917

Borz, S.A., Marcu, M.V., Cataldo, M.F. 2021. Evaluation of an HSM 208F 14tone HVT-R2 forwarder prototype under conditions of steep-terrain low-access forests. Croat J For Eng 42(2):185–200. Doi: 10.5552/crojfe.2021.775

Castellanos, A., Blanco, A.M., Palencia, V. 2007. Applications of Radial Basis Neural Networks for Area Forest. International Journal Information Theories & Applications 14 (1): 218-222.

Cataldo, M.F., Marcu, M.V., Iordache E., Zimbalatti, G., Proto, A.R., Borz, S.A. 2022. Performance of forwarding operations in biomass recovery from apple orchards. small-scale forestry 21:349–367. Doi:10.1007/s11842-022-09500-4

Costa, F.A., Sousa, R.A.T.M., Leite, A.M.P. 2003. Transporte rodoviário de madeira: um estudo de caso na Amazônia. In: Anais do VI Simpósio Brasileiro sobre Colheita e Transporte Florestal; Belo Horizonte. Belo Horizonte: UFV/ SIF. 349-363.

Duran, C., Çetindere, A., Aksu, Y.E. 2015. Productivity improvement by work and time study technique for earth energy-glass manufacturing company. Procedia Economics and Finance 26: 109-113.

General Directorate of Forestry (GDF), 2024. 2023 Administration activity report. Department of Strategy Development, Ankara.

Ghaffariyan, M.R. 2021. Predicting productivity of timber loading operations: a literature review. Silva Balcanica 22(2): 81-90. Doi: 10.3897/silvabalcanica.22.e69240

Gülci, N., Erdaş, O. 2018. Comparison of timber loading productivity between manual system and electric powered winch system. European Journal of Forest Engineering 4(1): 1-6.

Gülci, N., Erdas, O., Gülci, S., Akay, A.E. 2018. Productivity of a loader in mechanized loading operation in Osmaniye, Turkey. PEFOSS 2018 International Symposium "Man-Forest-Science", Sarejevo, Bosnia and Herzegovina. October 10-12.

Hartsch, F., Schönauer, M., Breinig, L., Jaeger, D. 2022. Influence of loading distance, loading angle and log orientation on time consumption of forwarder loading cycles: a pilot case study. Forests 13: 384. Doi: 10.3390/f13030384

Hildt, E., Leszczuk, A., Donagh, P.M., Schlichter, T., 2020. Time consumption analysis of forwarder activities in thinning. Croatian Journal of Forest Engineering 41(1): 13–24.

Karaman, A. 1991. Investigating time, productivity, and cost of Liebher 902 during loading and piling of logs in forest depots. Msc Thesis, Trabzon. 103 p.

Kewilaa, B., Tehupeiory, A., 2015. Effects of working time and the volume and weight of timber on productivity of log loader caterpillar type 966F and WL 980C. Wood Research Journal 6(1):8-13.

Louis L.T., Kizha A.R., Daigneault A., Han H.S., Weiskittel A. 2022. Factors affecting operational cost and productivity of ground-based timberharvesting machines: a meta-analysis. Current Forestry Reports 8: 38-54. https://doi.org/10.1007/s40725-021-00156-5.

Machado, C.C., Lopes, E.S., Birro, M.H.B., Machado, R.R. 2019. Transporte rodoviário florestal. 2. ed. Viçosa: Editora da Universidade Federal de Viçosa. 217 p.

Malinen, J., Laitila, J., Väätäinen, K., Viitamäki, K. 2016. Variation in age, annual usage and resale price of cut-tolength machinery in different regions of Europe. International Journal of Forest Engineering 27(2):95–102. Doi:10.1080/14942119.2016.1171964

Manner, J. 2021. What is (not) an operator effect in forest work science? Silva Fenn. 55: 1–4.
Mederski, P.S., Bembenek, M., Karaszewski, Z., Lacka, A., Szczepanska-Alvarez, A., Rosinska, M. 2016. Estimating and modelling harvester productivity in pine stands of different ages, densities and thinning intensities. Croat. J. For. Eng. 37: 27–36.
Minette, L.J., Souza, A.P., Fiedler, N.C., Silva, E.N. 2014. Carregamento e descarregamento. In: Machado C.C. Colheita florestal. 3. ed. Viçosa: UFV.
Mirkala, S.R.M., Naghdi, R. Time consumption and production cost of log loading in the hyrcanian forest using front-end loader. Silva Balcanica 18(1): 63-74.
Parajuli, M., Hiesl, P., Smidt, M., Mitchell, D. 2020. Factors influencing productivity and cost in the whole-tree harvesting system. Clemson Cooperative Extension, Land-Grant Press by Clemson Extension 1079: 1-8.
Proto, A. R., Macri, G., Visser, R., Harrill, H., Russo, D., Zimbalatti, G. 2018. Factors affecting forwarder productivity. European Journal of Forest Research, 137(2), 143–151. doi: 10. 1007/s10342-017-1088-6.
Puvanasvaran, A.P., Mei, C.J., Alagendran, V.A. 2013. Overall equipment efficiency improvement using time study in an aerospace industry. Procedia Engineering 68: 271-277.
Sable, S.R., 2014. A Study of labor productivity through application of stop watch time study method and most in skoda auto india private limited. PhD Thesis. SNDT Women's University. Nasık, India. 331 p.
Dos Santos, P.H.A., de Souza, A.P., da Cunha Marzano, F.L., Minette, L.J. 2013. Productivity and costs of eucalyptus wood extraction with Clambunk skidder. Rev. Árvore Vicosa-MG 37: 511–518.
Sporcic, M., Landekic, M., Susnjar, M., Pandur, Z., Bacic, M., Mijoc, D. 2023. Deliberations of forestry workers on current challenges and future perspectives on their profession-a case study from Bosnia and Herzegovina. Forests 14(4): 1-18. doi: 10.3390/f14040817.
Stankic, I., Porsinsky, T., Tomasic, Z., Tonkovic, I., Frntic, M. 2012. Productivity models for operational planning of timber forwarding in Croatia. Croat. J. For. Eng. 33: 61–78.
Strandgard, M., Mitchell, R. 2019. Comparison of cost, productivity and residue yield of cut-to-length and fuel-adapted harvesting in a Pinus radiata D. Don final harvest in Western Australia. New Zealand Journal of Forestry Science 49:1-9. Doi: 10.33494/nzjfs492019x37x
Strandgard, M., Mitchell, R. 2015: Automated time study of forwarders using gps and a vibration sensor. Croat. J. For. Eng. 36(2): 175–184.
Strandgard, M., Mitchell, R., Acuna, M. 2015. Impact of slope on forwarder load size and productivity. In Proceedings of the 48th FORMEC Symposium, Linz, Austria, 1 December, 101–105.
Tyulenev, M. Litvin, O., Cehlár, M., Zhironkin, S., Gasanov, M. 2017. Estimation of hydraulic backhoes productivity for overburden removing at Kuzbass Open Pits. Acta Montanistica Slovaca 22(3): 296-302.
Ünver, S., Usta, Y., Acar, H.H. 2024. Evaluation of post-fire salvage logging operations in terms of environmental damages and the timber industry's needs. 56th FORMEC, June 11-13, Gdansk, Poland.
Ünver-Okan, S. 2020. Modelling of work efficiency in cable traction with tractor implementing the least-squares methods and robust regression. Croat. J. For. Eng. 41(1): 109-117.

# Assessment of Urban Green Areas Using i-Tree Canopy

**Abdulwasa Abdiwali Hassan[1*], Abdullah Emin Akay[2], Zennure Uçar[3], Neşat Erkan[2]**

[1]City University of Mogadishu, K4-Square, Hodon District Mogadishu, Somalia
[2]Bursa Technical University, Faculty of Forestry, Bursa, Türkiye
[3]İzmir Katip Çelebi University, Faculty of Forestry, İzmir, Türkiye
[*] abdiwasac@cu.edu.so

## Abstract

Assessing urban green areas is crucial for sustainable urban development because they provide fundamentals benefits to the human being such as recreational opportunities and aesthetic value, reducing energy use with cooling effects, improving water and air quality, diverse wildlife habitat, and increasing human health and well-being. Advanced technology such as GIS and Remote Sensing has been applied to monitor, assess, and analyze land use/land cover and the vegetation changes in urban green areas by integrating spatial data. Specifically, i-Tree Canopy is widely used to estimate land use/land cover, especially the vegetation to classify ground cover types. Furthermore, i-Tree is a suite of freely-available software tools designed to assess the benefits and values derived from trees and forests. In this study, the conditions of green areas in the city center of Mogadishu (Somali) were evaluated and suggestions for the protection and development of the urban greenings were presented. "i-Tree" program was used to evaluate the spatio-temporal changes of green areas in the city center of Mogadishu by considering two time periods (2002 and 2023). The results indicated reduction in total green areas (Grass/Herbaceous and Tree/Shrub) from 26.40% to 24.20% over the 21-year period, as indicated by the i-Tree Canopy data, pointed to a gradual loss of green spaces due to urban expansion and infrastructure development.

***Key words:*** *Urban green areas, socio-economic impact, environmental sustainability, i-Tree Canopy*

## 1. Introduction

Urban green areas (UGAs) are essential components of urban landscapes globally, offering ecological, social, and health benefits that are crucial for enhancing the quality of urban life. As cities expand, the integration of these green spaces is vital for maintaining environmental balance and improving residents' quality of life. These areas provide essential services like air purification, temperature regulation, and recreational opportunities, which gain importance as urbanization accelerates and environmental challenges increase (Chukwu et al., 2023).

In places like Africa, especially Somalia, UGAs present both a challenge and a significant opportunity for sustainable urban planning. Mogadishu, the capital and largest city, faces unique challenges in incorporating green spaces into its urban fabric. This struggle is vital not only for environmental sustainability but also for the well-being of its residents. Although specific studies on Mogadishu are sparse, the general significance of UGAs in similar contexts indicates substantial potential benefits (Hassan and Akay, 2024).

Mogadishu presents a unique challenge in urban planning and green space availability. The city has seen rapid urbanization, combined with political instability and resource constraints, leading to a significant reduction in public green spaces. The existing green areas are poorly maintained and often inaccessible, exacerbating the urban heat island effect and limiting recreational opportunities for residents. The degradation of these areas highlights broader governance and public policy issues that have historically overlooked urban environmental management in Mogadishu (Hassan and Akay, 2024).

Assessing urban green areas is crucial for sustainable urban development because they provide fundamentals benefits to the human being such as recreational opportunities and aesthetic value, reducing energy use with cooling effects, improving water and air quality, diverse wildlife habitat, and increasing human health and well-being (Merry et al., 2014; Ucar et al., 2016; Parmehr et al., 2016). With technological advancements, new tools and techniques have emerged to improve the management and assessment of urban green areas. Following the assessment methods, specific tools have been developed to enhance accuracy and efficiency by integrating GIS and RS into their system. For example, i-Tree suite of tools is one such example, which uses a random points sampling approach. The i-Tree Canopy software was developed by the USDA Forest Service to assess the ecosystem services provided by urban forests (Nowak, 2011). It offers various applications like MyTree, Design, Landscape, Canopy, and Eco, enabling users to measure and analyze ecosystem services, tree canopies, and carbon storage effectively (i-Tree, 2024).

In this study, the conditions of green areas in the city center of Mogadishu were evaluated and suggestions for the protection and development of urban greenings were presented. "i-Tree" program was used to evaluate the spatio-temporal changes of green areas in the city center of Mogadishu by considering two time periods (2002 and 2023).

## 2. Material and Methods

### 2.1. Study Area

The study area will be city center of Mogadishu, Somali. Mogadishu, capital, largest city, and a major port of Somalia. During the 1990s war in Somalia caused widespread destruction in the city and in public green areas around the city center. Some of them have not been recovered after the war, they have been converted into buildings or other residential structures instead.

### 2.2. Public Green Space Assessment Using i-Tree

To appropriately manage urban green areas, we employed the i-Tree Canopy tool to assess spatio-temporal changes of urban green areas in the city center of Mogadishu for two time periods (2002 and 2023). The i-tree tool has been using the latest Google Earth Pro images while deciding land use land cover within study area. In our study, the Google Earth Pro images, which have been used to assess the urban green areas, have images from October. We also used Google Earth images from April 2002 in order to assess the LULC changes, particularly in urban green areas (Figure 2 and Figure 3).

i-Tree Canopy is designed to allow users to easily and accurately estimate trees and other cover classes (e.g., grass, building, roads, etc.) within their city or any specified area (Table 1). The tool works by randomly placing sample points (the number determined by the user) onto Google Earth imagery. Users then classify each point according to its cover class. Users can define any cover classes they prefer, and the program will show estimation results throughout the interpretation process.


Figure 1. The city center of Mogadishu in Somalia

Figure 2. The satellite images of Mogadishu for April 2002

Figure 3. The satellite images of Mogadishu for October 2023

Table 1. Land cover classes considered in i-Tree program

| Cover Classes | Abbreviations |
|---|---|
| Tree/Shrub | T |
| Grass/Herbaceous | H |
| Impervious Buildings | IB |
| Impervious Road | IR |
| Impervious Other | IO |
| Water | W |
| Soil /Bare Ground | S |

**2.3. Data collection**

In the first stage, the border of the city center of Mogadishu was drawn onto a base map captured by the i-Tree Canopy. Then, in the i-Tree Canopy interface, 500 random sampling points, distributed evenly around the study area, were generated. The selection of 500 points is supported by i-Tree recommendations, which suggest a range of 500-1000 points to balance data reliability and workload efficiency, aiming to achieve an acceptable standard error (SE) of less than 2.5-2% (Parmehr et al., 2016).

Each point assigned to land cover classes was recorded in the i-Tree Canopy (Figure 4). After classifying LUCL for 2023, Sample point data layer was exported from i-Tree Canopy as ".klm" format and opened in Google Earth Pro (Figure 5). The change over time was assessed using a pairwise comparison approach, which aligns with the methodologies used in studies by Merry et al. (2014) to track changes in urban tree cover over significant periods. This method provides a robust framework for analyzing transitions in tree cover, drawing on historical and contemporary data to evaluate urban forestry dynamics effectively. Then, each sample point was classified in a 2002 image and its associated land cover type was assigned in the i-Tree Canopy database. Therefore, a new land cover database was generated for 2002.

Figure 4. Selected sample points on 2023 image

Figure 5. The sample points on 2002 images from Google Pro

## 3. Results and Discussion

### 3.1. Urban green area results for 2002

In 2002, the landscape of Mogadishu exhibited a considerable amount of tree/shrub areas, which covered 411.39 hectares, equivalent to 26.40% of the studied urban green areas (Table 2). This substantial presence of urban green areas underscored their vital role in providing ecological benefits and enhancing urban air quality. Notably, impervious structures like buildings dominated 37.60% of the area, totaling 585.74 hectares, reflecting the urban framework at that time. Roads accounted for 12.40% with an area of 191.66 hectares.

### 3.2. Urban green area results for 2023

In 2023, the landscape of Mogadishu exhibited a considerable amount of tree/shrub areas, which covered 376.97 hectares, equivalent to 24.20% of the studied urban green areas (Table 3). This substantial presence of urban green areas underscored their vital role in providing ecological benefits and enhancing urban air quality. Notably, impervious structures like buildings dominated 51.94% of the area, totaling 807.80 hectares, reflecting the extensive urban construction at that time. Roads accounted for 14.95% with an area of 232.43 hectares.

Table 2. Land cover assessment in Mogadishu (2002)

| Cover Class | Points | % Cover ± SE | Area (ha) ± SE |
|---|---|---|---|
| Grass/Herbaceous | 1 | 0.20 ± 0.20 | 2.59 ± 2.59 |
| Impervious Buildings | 188 | 37.60 ± 2.17 | 585.74 ± 33.67 |
| Impervious Other | 16 | 3.20 ± 0.79 | 49.21 ± 12.95 |
| Impervious Road | 62 | 12.40 ± 1.47 | 191.66 ± 23.31 |
| Soil/Bare Ground | 100 | 20.00 ± 1.79 | 310.80 ± 28.49 |
| Tree/Shrub | 132 | 26.40 ± 1.97 | 411.39 ± 31.08 |
| Water | 1 | 0.20 ± 0.20 | 2.59 ± 2.59 |
| Total | 500 | 100.00 | 1553.98 |

Table 3. Land cover assessment in Mogadishu (2023)

| Cover Class | Points | % Cover ± SE | Area (ha) ± SE |
|---|---|---|---|
| Grass/Herbaceous | 2 | 0.40 ± 0.28 | 5.18 ± 3.63 |
| Impervious Buildings | 278 | 55.71 ± 2.22 | 807.80 ± 29.87 |
| Impervious Other | 4 | 0.80 ± 0.40 | 40.30 ± 10.24 |
| Impervious Road | 66 | 13.03 ± 1.51 | 232.43 ± 23.21 |
| Soil/Bare Ground | 91 | 18.24 ± 1.73 | 299.35 ± 26.59 |
| Tree/Shrub | 59 | 11.82 ± 1.45 | 376.97 ± 28.84 |
| Water | 0 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Total | 500 | 100.00 | 1553.98 |

## 4. Conclusion

In analyzing the urban green space dynamics of Mogadishu between 2002 and 2023, this study has identified significant changes in the distribution and quality of these areas. The reduction in total green areas (Grass/Herbaceous and Tree/Shrub) from 26.40% to 24.20% over the 21-year period, as indicated by the i-Tree Canopy data, pointed to a gradual loss of green spaces due to urban expansion and infrastructure development. The observed increase in impervious surfaces-particularly buildings, which grew from covering 37.60% of the area in 2002 to 51.94% in 2023-highlighted a significant urban intensification. This development pattern correlated with increased impervious surfaces contributing to decreased urban tree coverage. By comparing these changes and trends with those documented in similar contexts, this discussion aimed to contribute to a more comprehensive understanding of how urbanization impacts green spaces in post-conflict urban settings like Mogadishu. This is crucial for informing policy and planning, ensuring that urban development sustains, rather than detracts from, the environmental and social health of the city. The use of GIS and i-Tree Canopy tools has allowed for a precise assessment of changes in land cover over time, revealing a decline in green coverage and a corresponding increase in impervious surfaces. These shifts underscored the pressing need for strategic urban planning that integrates sustainable green space development to counteract the adverse effects of urban sprawl and environmental degradation.

## References

Chukwu, I.N., Uzonnah, O.E., Uzuegbunam, F.O., Ibem, E.O. 2023. Assessment of public attitude towards green infrastructure and its predictors in urban areas of Ebonyi State, southeast Nigeria. Environment, Development and Sustainability. http://doi.org/10.1007/s10668-023-03898-3.

Hassan, A.A., Akay, A.E. 2024. Urban green areas in Africa: Case of Somalia. In Proceedings of the 8th International Icontech Congress on Innovative Surveys in Positive Sciences (pp. 454-460). Azerbaijan: Azerbaijan Cooperation University, March 16-18.

i-Tree. 2024. Retrieved 17 March 2023, from https://www.itreetools.org

Merry, K., Siry, J., Bettinger, P., Bowker, J.M. 2014. Urban tree cover change in Detroit and Atlanta, USA, 1951–2010. Cities, 41, Part A, 123-131.

Parmehr, E.G., Amati, M., Taylor, E.J., Livesley, S.J. 2016. Estimation of urban tree canopy cover using random point sampling and remote sensing methods. Urban Forestry & Urban Greening, 20, 160-171. https://doi.org/10.1016/j.ufug.2016.08.011

Uçar, Z., Bettinger, P., Merry, K., Siry, J., Bowker, J.M. 2016. A comparison of two sampling approaches for assessing urban forest canopy cover from aerial photography.

# Stump Harvesting Operations: Examples from the Mediterranean Region

**Mehmet Eker[1], Raffaele Spinelli[2*], Hakan Durgun[1]**

[1]Isparta University of Applied Sciences, Faculty of Forestry, Forest Engineering Dept., Isparta, Türkiye
[2]Institute of BioEconomy, The National Research Council, Sesto Fiorentino, Italy
[*]raffaele.spinelli@ibe.cnr.it

**Abstract**
The increasing demand for woody biomass has revived tree stump collection. Stump biomass is a viable raw material for the bioenergy sector, and could also be used for extracting valuable chemicals, such as resin. However, the harvesting of stump biomass requires heavy equipment and is a practice that has received much criticism for its potential negative effects on the forest topsoil. Stump harvesting requires specialised tools and equipment, and a similarly specialized supply chain, both of which add a level of complexity to the supply chain. Hence the interest in scoping technology alternatives across the Mediterranean region, and more in general across the globe. Therefore, the aim of this study is to compare the stump harvesting operations, techniques and technologies employed in Türkiye (TR), Italy and generally in other countries. For that purpose, the Authors reviewed the findings of past studies on the subject, obtaining detailed information on the collection process, the equipment used and the results achieved. According to the results of the review, heavy excavators seem particularly effective if fitted with specially manufactured attachments, which minimize soil disturbance compared to the conventional bucket. Of course, stump harvesting is a specific practice limited to plantations on flat terrain and should not be practiced on slopes, unless as part of a general reclamation project. The main challenge with stump harvesting is soil contamination, which can be minimized by mechanical stump cleaning, sieving of the comminuted product or by prolonged open-air storage aimed at weathering the soil off the stumps.

***Keywords:*** *Stump harvest, stump biomass, work technique, excavator based operations*

## 1. Introduction

The search for renewable and clean energy sources triggers the use of low value-added woody biomass as a primary energy source in the forestry sector (Eker, 2014). As you know, forest biomass is a raw material for many sectors (Suadicani and Talbot, 2010). Woody biomass is also a primary resource for the energy sector (Demirbaş, 2008) in terms of both classical and modern usage technologies (Figure 1). The distribution/sharing ratio of this resource between sectors is not equal and is ranked from high added value to low value depending on market conditions (Sathre and Gustavson, 2009) (Figure 2). The fact that woody biomass is used as a building-reinforcement and engineering material both increases its acquisition (purchase) costs and leads to supply shortages for some sectors such as bioenergy. For this reason, the bioenergy sector also turns to woody biomass, which has low added value (Richardson et al., 2002; Perlack et al, 2005).

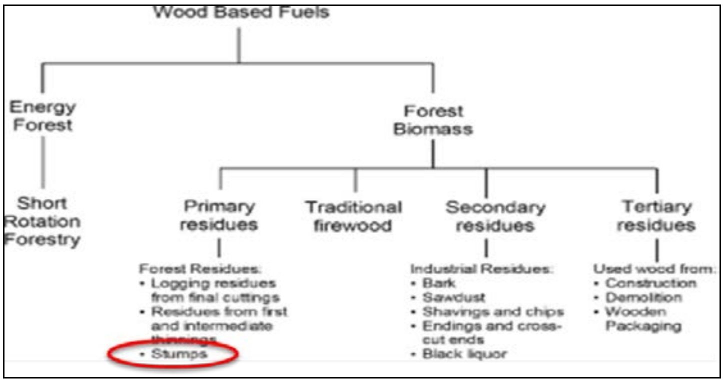



Figure 1. Woody biomass as source of primary energy (Röser et al., 2008)


Figure 2. The distribution of woody forest products as to value adding

Stump biomass is also one of these resources (Spinelli et al., 2005). Stump biomass is a term that refers to the above-ground and underground parts of the bottom stump left after the tree is cut down and the thick root biomass with together (Eker and Eryılmaz, 2023). In this study, only the term of stump biomass is used instead of stump and root biomass. In Figure 3 (at the left side of which), the utilizable underground and aboveground stump and the thick lateral and main roots with commercial value was picturized out in a circle.

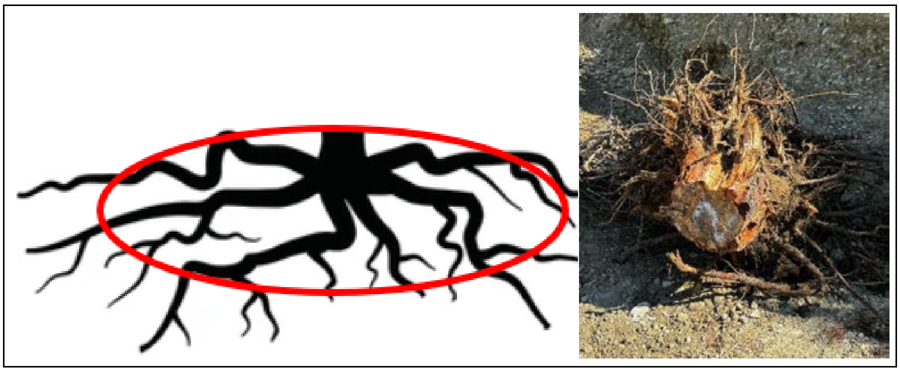


Figure 3. Stump (and root) biomass for utilization (left; https://www.shutterstock.com/tr/ )

In the last decade in TR, stump-root harvesting has started suddenly and rapidly in areas allocated as industrial plantations (Figure 4). In TR, stump harvesting has been carried out in brutian pine (*Pinus brutia* Ten) forests where site cleaning or soil preparation is carried out for the purpose of establishing industrial plantations (Eker and Eryılmaz, 2023). Industrial plantations are operated with fast-growing tree species in order to meet the wood raw material demand, especially on the demand of leaf and chipboard industry (Erkan, 2021). An action plan had been prepared under the name of "Industrial Afforestation Studies Action Plan" and covering the period of 2013-2023, aimed to produce industrial wood using intensive silvicultural methods in places with good bonitet (site class) (GDF, 2013). Forest lands, treasury lands and agricultural lands were listed as potential plantation areas in the action plan, and the use of brutian pine tree species was planned especially in the Mediterranean and Aegean regions (145,000 ha). Plantations have already been carried out in nearly 50% of these areas. In areas where plantations would be established with an average slope of less than 25%, tree stump/roots removed from the area for soil processing by machinery. These areas are source of commercially utilizable stump biomass.

Figure 4. Stump harvesting operations in Mediterranean region of TR

Although the need for stump biomass fluctuates over the years due to the change in the market economy in the forest products industry, stump harvest can be carried out in areas with technical and economic potential. Despite its economic importance in recent years, there is very little knowledge on the theoretical and practical scale of stump harvesting. The rationale for this study was based on the lack of knowledge on; feedstock capacity (potential; inventory; availability; etc.), supply possibilities (accessibility, technology, recovering, etc.), utilization options (converting, industry, infrastructure, demands, etc.).

The purpose of this study is to evaluate and provide information on stump harvest operations, techniques and technologies applied in Mediterranean countries such as TR and Italy, as well as in other countries. This paper has been prepared as part of an ongoing study on stump biomass has been carried out within the scope of completing the lack of information on both scientific and practical scales on raw material inventory, appropriate work technique, appropriate tool and equipment selection, and logistics.

Within the framework of the woody biomass supply chain, such a study was planned by considering how solutions have been developed in Italy and other countries for the problems encountered in stump harvesting in TR. The methodology followed in carrying out this study, which covers the process followed for stump harvest, what the work technique is, the characteristics of the tools and equipment used, how they are operated in the field and what kind of problems are encountered; it consists of compilation of information obtained from various sources such as literature information, previous research results, field observations, and good practice guidelines..

**2. Methodology for Stump Harvesting**

Stump harvesting works begin after the removal of commercial wood products in the forest stand to be converted into industrial plantation is completely removed. The stump biomass in the forest stand belonging to the state forestry administration is sold to private companies through tender methods. Private companies use own harvesting technologies and techniques to uproot the stump biomass in the field within a specified period, remove it from the compartment and transport it to their own storage.

In TR, stump harvesting technology is based on the use of hydraulic crawler excavators. Excavators of various sizes are used for stump harvesting. While excavators weighing more than 20 tons are generally used for removing and processing roots, excavators weighing 10-20 tons can be used for clearing the roots from the soil and loading them onto vehicles. For example, 32-ton excavators are generally used for uprooting and pulling the stump-root system with ripper, bucket and splitter. However, lighter excavators can be used for grapple rake used for collecting roots, shaking them to shed soil and loading them onto trucks. Table 1 shows some excavator brands and features used during stump harvesting in some stands in the Mediterranean Region in TR.

Table 1. Excavators for stump harvest operations and their features (Eker and Eryılmaz, 2023)

| Example of Excavators' Brand and Model | Weight (ton) | Attachment |
|---|---|---|
| Hidromek HMK 220LC | 23.85 | Riper |
| Komatsu PC300 | 32 | Riper |
| Hitachi Zaxis 300 LCH | 32.2 | Bucket |
| Hitachi Zaxis 300 LCH | 32.2 | Shear (Splitter) |
| Sumitomo SH 210 | 22.2 | Bucket |
| Case CX130b | 12.6 | Grapple Rake |

Stump harvesting works are carried out by mounting various types and sizes of attachments on the excavators. The equipment used on the excavators may vary depending on the available current attachments of the company (contractor) undertaking the stump harvesting work, the thickness of the bottom log (aboveground stump diameter), the structure of the land and soil layer, and also the skill of the operator.

One of these is the single-tooth ripper head. With this attachment, roots can be uprooted and removed. Another equipment used in TR is the shear/splitter, which is produced in the local industry and widely used in many countries in the world with some manipulated versions. With this attachment, the roots are divided into at least two pieces after being removed from soil, making it easier to both clean them from the soil and transport them to the storage areas (Eker and Eryılmaz, 2023).

Figure 5. Excavator attachments for stump harvest: Ripper (at left) and Splitter/shear (at right)

Another excavator attachment used during stump harvesting is the bucket. Buckets with a thin mouth, which are used for general purposes and are mostly preferred in digging channels, are used in stump uprooting operations. Again, depending on the inventory of the contractor undertaking the job, grapple rakes are another attachment used to clean the uprooted stumps from the soil, throw them to the side of the road, collect them there and load them into the truck (Figure 6). Without changing these heads used in excavators, the uprooted stumps are dragged, pushed or thrown on the ground and conveyed to the side of the road. On the side of the road, loading can be done on trucks with other excavator equipment. In some places, loading is also done with backhoe-mounted grapple buckets (Figure 7).


Figure 6. Excavator attachments for stump harvest: Bucket (at left) and Grapple Rake (at right)


Figure 7. Backhoe during the loading of harvested stump biomass at the landing

The process for stump harvesting with excavators and equipment; at first, the excavator operator digs and removes the root system from the soil, in other words, uprooting. Then, it cleans the stump-root with various spears to remove the soil and stone integrity between the coarse and fine roots (Figure 8). If the uprooting work is done with a splitter or if there is a splitter on an auxiliary excavator, the roots are divided, and a kind of volume reduction and cleaning process is performed. Then, the stumps are conveyed to the roadside with the help of the excavator. The stump biomass is piled up on top of each other with the same or a different vehicle on the roadside and the road is kept open to traffic. If there is a splitter, shredding can also be done on the roadside. Here, the same vehicle or different vehicles load trucks or lorries (Eker and Eryılmaz, 2023). The stump biomass brought to the bioenergy facility is sometimes divided into two or three pieces depending on the structure of the business and stored in the open air. Biomass can sometimes be left for up to a year to be cleaned by rain or irrigation and to remove moisture. Then, it is crushed by passing through a chipping machine and burned to produce heat and power.


Figure 8. Excavator based stump harvest operations with different attachments

When we look at the work technique followed in this process (Table 2); first, the field is cleaned of cutting residues in advance so that the excavator operator does not have difficulty in searching and finding the stumps, or at the beginning of the work, the operator cleans the area by sweeping with the excavator arm for a certain work area. After the stump is found, the operator softens the right and left of the stump with the attachment and then grabs the stump-root and removes it. After the stump with root system are removed from the ground, they are shaken, pushed, aired, etc. depending on the attachment used, they are tried to be cleaned from the soil and stones. Then, depending on the attachment to the boom of the excavator, they are swept and dragged on the ground or taken into a bucket and pushed or thrown from top to bottom. After the stump is removed, the excavator operator fills the gap with the surrounding excavation material, the soil, and closes and levels its surface to be at the same level as the natural surface. If the stump removal is done with a splitter or if there is a splitter in the field, the stumps can be divided into two parts where they are removed or on the roadside, and both cleaning and shredding can be carried out. If there is a grapple rake on a second excavator, the roots can be cleaned and brought to the roadside. The roots are piled on top of each other with the excavator and its attachments on the roadside and loaded and transported (Figure 9) (Eker and Eryılmaz, 2023).

**3. Result and Discussion**

If it is evaluated the stump harvesting in TR, a Mediterranean country, with the practices in Italy and other countries;

- In general, utilizable biomass amount obtained from stump harvest operations is approximately 20% of the above-ground biomass of a tree. This varies depending on the diameter, age, etc. of the tree (Spinelli, 2011).
- Stump harvesting is not applied everywhere. Stump removal is operated in only site preparation for industrial plantation area. Furthermore, only commercial biomass is removed from the forest site.

Table 2. Example of workflow for stump harvesting

| Work Elements | Definition *(for riper, bucket and splitter)* |
|---|---|
| Moving and booming out | The excavator starts, and the operator sees the stump and moves towards the stump (or from one stump to another) and when he arrives at the stump side, the excavator takes the working position and extends the boom towards the stump. |
| Side excavation | The right and left sides of the stump are excavated with attachment and the lateral root connections are cut and weakened. |
| Uprooting | The excavator's bucket or ripper is placed on the back side of the stump and pushed under the root and the stump biomass is lifted, pulled, and uprooted from the soil and brought above the soil. |
| Cleaning | The uprooted stump covered with stones and soil is cleaned by dragging it back and forth on the ground with the ripper head and shaking it. Or the stump taken with the excavator bucket is shaken while it is in the bucket, and it is thrown and picked up several times to remove soil and stones. |
| Extraction | Pushing, rolling, and shoveling of the cleaned stump towards the roadside by sweeping it on the ground with the boom head. Or the uprooted stump mass is picked up with a bucket and thrown, shoveled and rolled towards the roadside with the help of the boom length. |
| Filling and smoothing | The soil from the hole formed by the removal of the stump-root and the soil from the side excavations is swept with the bucket and filled into the hole and the ground is simply smoothed. |
| Splitting | The excavator with splitter (shear) is used to cut the roots into 2 or 4 pieces on the stand or roadside with the help of cutting shears and to remove the soil and stone mass from stump-roots. |

Figure 9. Sorting and loading of stump biomass with excavator and hauling with trucks

- Stump harvesting includes ecological risks. No matter where it is applied, stump harvesting contains ecological risks (Hyvönen et al., 2016; Persson and Egnell, 2018) and it is seen that various risks are posed to the forest soil in the practices in TR, as well (Figure 10). It is known that similar risks exist in other countries during the stump harvest (Persson, 2017). However, in the stump harvesting practices carried out in TR, the operator fills the root gaps with soil after removing the roots and tries to repair the landform by levelling the surface, even if only a little.
- No regulations to design stump harvest operations in TR.

Figure 10. Topsoil excavation after uprooting stump biomass

If it is evaluated the applications in TR with Italy or other countries regarding stump harvest operation technology:

- The stump harvesting technology used in TR is like other countries. Although various stump removal and harvest vehicles and apparatus have been developed in some countries nationally and regionally, excavators are seen to be the dominant vehicle. For this reason, excavator heads can be produced according to features such as tree type, soil structure, stump structure, etc.
- In TR, both classical attachments are used and local-scale stump harvest apparatus can be produced (such as splitter). In literature, various equipment can be mounted for uprooting, splitting, cleaning, piling and filling-smoothing operations. Such as; stump lifting head (stump splitter, stump puller), stump splitting attachment, destumping head (with shear), stump harvesting head, stump rake, stump processor, demolition grapple. In TR; ripper, bucket, grapple rake and shear has been used. So, the stump harvesting operations in TR is partially different from other countries because it is generally based on bucket. But it is not a contrary practice due to bucket is a commonly available head.
- In some countries, for backfilling and levelling the ground surface are used modified metal part in excavators. In TR, backfilling and smoothing is done with the same excavator head that is used to harvest stump.
- In TR, the splitting (shear) head is rarely used for stump uprooting because it is not effective (Eker and Eryılmaz, 2023). It has been used in splitting after uprooting, extraction, and loading of stumps. In some countries the different version of the heads has been reported as an effective (Forest Research, 2009; Laitila et al., 2013; Spinelli, 2011) (Figure 11).
- Machinery Technologies are used in various countries (Mitchell, 2009). In poplar plantations in Southern Europe, a mechanized root harvesting system was developed (Spinelli 2011).
- A prototype of a wheeled mechanism was developed in Italy with a tractor to fell the tree together with its roots (Spinelli et al., 2005).
- In Italy, an auger designed to fit on the rear end of an agricultural tractor and it could be mass-produced and mounted on excavators
- In the last 50 years, typical vehicles and heads for stump harvesting are heavy duty crawler excavators. The weight is generally varied between 17-26 tons in other countries such as BC, Finland, Sweden, and the UK (Berg, 2014).

Figure 11. Excavator attachments as a splitter in different countries for stump uprooting

The work technique of stump harvesting in TR is similar with other countries. The stump harvesting process involving the uprooting, splitting, and cleaning of the stump biomass is the similar between TR and other countries. However, stump biomass is left at the stand edge or roadside with a long time before being transported, As well, it can be splitted at the roadside (comminution) in other countries. Differently, in TR, splitter head is rarely used in stand and splitting is generally realized at the plant before storing. The practice for the soil and stone mass adhering from the uprooted stump is similar in many countries and TR. Soil and stone are mechanically removed by the uprooting vehicle or another auxiliary vehicle by shaking the stump-root biomass. Stump harvesting technique may vary depending on various factors: stand characteristics, topographical conditions, the excavator used and attachments, the content of the work, operator skills, and local conditions. In TR, the stump biomass supply chain is like with the literature in terms of system structure, sequence of operations, and contents. However, in TR, the order of the work pieces and the operation content varies depending on the local technology. For example, splitting can be performed in both harvesting, transport and storage processes. In TR, the extraction work step can be considered as a sub-process, which is separated from the harvesting work step and considered within the transport process. Because the main machine with the same attachment is used for removing uprooted stumps to roadside. Sometimes, loading is also operated with same vehicle.

**4. Conclusion**

The stump harvesting has both advantages and also disadvantages (technical, ecological and economic) in TR like that in other countries. Some measures should be taken to reduce ecological risks, which are the biggest handicap. Stump harvesting should only be done in flat and nearly flat (Slope < 15%) forest stands. Of course, stump harvesting is a specific practice limited to plantations on flat terrain and should not be practiced on slopes, unless as part of a general reclamation project. As applied in many countries, using an excavator to increase the amount of recoverable stump biomass seems to be an effective method. In operations performed with an excavator bucket, attention should be paid to cleaning the soil in the stump near the root pits and filling the pits. Heavy excavators seem particularly effective if fitted with specially manufactured attachments, which minimize soil disturbance compared to the conventional bucket. A suitable excavator type and attachment selection should be made according to factors such as root stump diameters, soil structure, terrain structure, etc. The main challenge with stump harvesting is soil contamination, which can be minimized by mechanical stump cleaning, sieving of the comminuted product or by prolonged open-air storage aimed at weathering the soil off the stumps. Waiting the stumps at the stand borders or on the sides of the road during the rainy season may provide technical and ecological benefits. Splitting/comminution work should be done before transportation in terms of reducing bulk volume.

**References**

Berg, S. 2014. Technology and Systems for Stump Harvesting with Low Ground Disturbance. Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala, 83p.

Demirbaş, A. 2008. Importance Of Biomass Energy Sources for Turkey. Energy Policy. 36(2): 834–842.

Eker, M., Eryılmaz, A. 2023. Stump Harvesting Methods in Turkish Forestry. B.N. Rashid (Ed.), Strategic Research in the Field of Sustainability-Based Agriculture and Forestry. Klaipeda: SRA Academic Publishing. 25-62 p.

Eker, M. 2014. Trends in Woody Biomass Utilization in Turkish Forestry. Croatian Journal of Forest Engineering. 35(2): 288-270.

Erkan, N. 2021. Evaluation Of the History Of Industrial Plantation In Turkey. Turkish Journal of Forestry Research. 8(2): 108-116.

Forest Research, 2009. Stump Harvesting: Interim Guidance on Site Selection and Good Practice. The Research Agency of the Forestry Commission, Edinburgh. 19 p.

GDF (General Directorate of Forestry), 2013. Endüstriyel Ağaçlandırma Çalışmaları Eylem Planı (2013-2023), Orman Genel Müdürlüğü Yayını, Ankara.

Hyvönen, R., Kaarakka, l., Leppälammi-Kujansuu, J., Olsson, B.A., Palviainen, M., Vegerfors-Persson, B., Helmisaari, H.S. 2016. Effects of Stump Harvesting on Soil C and N Stocks and Vegetation 8-13 Years after Clear-cutting. Forest Ecology and Management. 371:23-32.

Laitila, J., Ranta, T., Asikainen, A. 2008. Productivity of Stump Harvesting for Fuel. International Journal of Forest Engineering. 19(2): 37–47.

Mitchell, D. 2009. Stump Harvesting. 32nd Annual Meeting of the Council on Forest Engineering (COFE). 15-18 June, California, USA.

Perlack, R.D., Wright, L.L., Turhollow, A., Graham, R.L., Stokes, B., Erbach, D.C. 2005. Biomass as Feedstock for Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. Oak Ridge National Laboratory. ORNL/TM-2005/66. Oak Ridge, Tennessee, USA.

Persson, T., & Egnell, G. 2018. Stump Harvesting for Bioenergy: A Review of Climatic and Environmental Impacts in Northern Europe and America. Wiley Interdisciplinary Reviews: Energy and Environment. 7(6): e307.

Persson, T. 2017. Stump Harvesting for Bioenergy - Methods and Environmental Effects. Scandinavian Journal of Forest Research. 32(3): 201-203.

Richardson, J., Björheden, R., Hakkila, P., Lowe, A. T., Smith, C. T. 2002. Bioenergy From Sustainable Forestry: Guiding Principles and Practice. Dordrecht: Springer Netherlands.

Röser, D., Asikainen, A., Rasmussen, K.R., Stupak, I. 2008. Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on The Baltic and Nordic Countries. Managing Forest Ecosystems, Volume-II, Netherlands. 232 p.

Sathre, R., Gustavsson, L. 2009. Process-based Analysis Of Added Value In Forest Product Industries. Forest Policy And Economics. 11: 65-75.

Spinelli, R. 2011. Supply Of Wood Biomass for Energy Purpose: Global Trends and Perspectives. In: 22nd Annual Meeting of the Club of Bologna, Hannover, Germany. 2011.

Spinelli, R., Nati, C., Magagnotti, N. 2005. Harvesting and Transport of Root Biomass from Fast-growing Poplar Plantations. Silva Fennica. 39(4): 539–548.

Suadicani, K., Talbot, B. 2010. Extracting and Chipping Hardwood Crowns for Energy. Scandinavian Journal of Forest Research. 25(5): 455-461.

# Key Issues That Need to be Addressed for Successful Biomass Harvesting and Utilization

**Mehmet Eker[1], Hakan Durgun[1], Han-Sup Han[2*]**

[1]Isparta University of Applied Sciences, Department of Forest Engineering, Isparta, Türkiye
[2]Ecological Research Institute, Northern Arizona University, Flagstaff, Arizona, USA
[*] Han-Sup.Han@nau.edu

## Abstract

For ecological and economic reasons, many efforts are being made to harvest and utilize woody biomass resources in traditional or innovative ways. The type, quantity, quality, etc. of usable biomass obtained from various forest management practices are highly variable, depending on many factors. Therefore, woody biomass supply chain logistics have different applications according to forest management objectives and local biomass market conditions. These differences can serve as examples of good practice in sharing innovative practices and providing solutions related to biomass harvesting and utilization in a global scale. The purpose of this study was to summarize the current practices of biomass harvesting and utilization in Türkiye and compare it with the biomass operations in the United States. For this purpose, the situation of the two countries including biomass inventory, biomass supply and utilization, and aspects of good practice examples were summarized. Since forest management practices are taking place in public forestlands in Türkiye, the product range of woody biomass is determined by state-run forest enterprises which emphasize ecological benefits, forest markets, local economy, and best management practices for enhanced biomass harvesting and utilization. We have identified and summarized key issues in biomass harvesting and utilization, including successful marketing woody biomass, enhancing biomass harvesting operations logistics, providing employment opportunities for local communities, and increased utilization of biomass for production of bioenergy and biobased products.

***Keywords:*** *Biomass harvesting, woody biomass, bioenergy, public forest management, biobased products*

## 1. Introduction

Wood products obtained from forest trees has been used for various purposes since the existence of mankind. It has always maintained its primary raw material feature for different purposes, it is generally an important natural resource. Moreover, wood as a raw material is currently a valuable source for meeting various needs/demands of society (Strykowski, 2013). Their economic values can cause vertical and horizontal displacement of the woody products between the areas of use cyclically. Although market demands change the range of woody products supplied and their intensity of use, mostly very high value forest products are always in demand (Figure 1).


Figure 1. Value pyramid of biomass (left: compilation from web; right: Klavins et al., 2023)

Many triggering factors such as the increasing world population, the decrease in fossil fuels and their cumulative environmental effects, and global climate change put woody biomass on the list of primary energy sources due to its clean and renewable nature. When it is desired to obtain energy with from woody biomass with classical and modern methods, woody resources with very low added value in the market can mostly be used (Eker, 2014). Because product distribution/sharing limits the woody biomass resources that can be used in bioenergy in many countries, as in Türkiye (ReportLinker, 2024). Due to the market economy, procurement costs and sales prices have a direct effect on the value and utilization of wood.

However, the available woody biomass resources are limited, and the usage capacity may vary under the influence of technical-economic-social and institutional factors. At this scale, low-value primary forest residues (logging residues, small diameter trees, treetops, stumps) may be the most important bioenergy source (Figure 2, 3, 4, and 5).

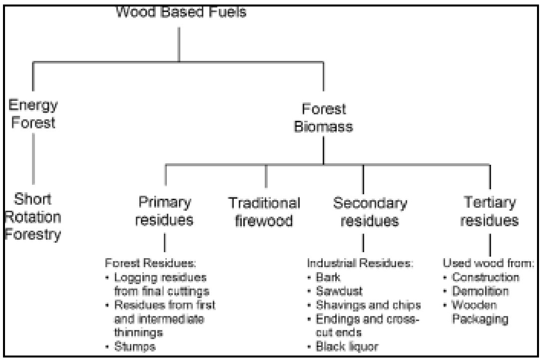



Figure 2. Source of woody biomass (Röser et al., 2008)

Figure 3. Old stumps for bioenergy

Figure 4. Small diameter trees (at left) and treetops (at right) for energy biomass

Figure 5. Logging residues sorted (at left) and slash (at right)

Forest residues are usually left on the forest floor after wood harvesting. Occasionally some of the larger waste wood had been removed as firewood for domestic consumption (eg. in Türkiye) but finer or residual part of this woody material generally left in stand (Figure 6). In order for biomass to be used for energy purposes to have a sustainable potential, it must have both theoretical, technical and economic potential, and also ecological and social application potential (Figure 7). Therefore, forest residue biomass for energy purposes must contain available energetic value and must not harm the biogeochemical cycle of the forest when removed from the stand. The use of woody biomass for energy purposes, that is, its implementation potential and sustainable utilization depend on many factors. If the economic supply potential of woody biomass, which has theoretical and technical potential, is low, a utilization problem may be encountered. The same product can be used even if it is economical but does not have ecological and social potential.

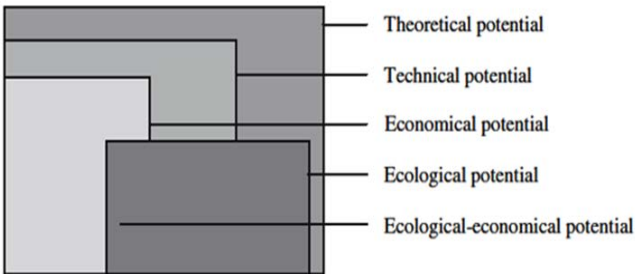



Figure 6. Sorted residues Figure 7. Taxonomy for Implementation potential

The purpose of this study was to summarize the current practices of biomass harvesting and utilization in Türkiye and compare it with the biomass operations in the United States. In this context, it was tried to reveal how and from which sources woody biomass for energy purposes can be provided in Türkiye, what has been done for this and what problems are encountered in establishing a supply system, and by simply comparing these with the applications implemented in the USA, some solution suggestions for the key problems were presented.

## 2. Recoverable Feedstock Capacity in Türkiye

When it is examined whether there is utilizable capacity of forest biomass for classical and modern energy production in Türkiye, it can be easily understood through sufficient forest resources (23.4 M ha), standing tree volume (1.77 B $m^3$), annual increment (50.14 M $m^3$) and annual wood production amount (average 25 M $m^3$) (GDF, 2024). From an economic perspective, wood has a product value as a commercial material. However, the demand of the society for wood is more than the supply. Most of this demand requires the use of harvested wood as industrial material. In fact, even fuel wood has gained industrial value as fiber-chip wood in recent years (GDF, 2024).

However, according to some generally accepted metrics, the annual biomass potential of Türkiye is estimated as 32 Mtoe (Million tonne(s) of oil equivalent) and total recoverable potential of which is anticipated as 17 Mtoe. Total biomass consumption in Türkiye has been calculated under 5 Mtoe/year. The content of recoverable biomass capacity is also including forest biomass. As a biomass source, annual potential of forest residues 18 Mtons (5,4 Mtoe). According to much repeated knowledge in Türkiye; the natural gross potential for energy is 135–150 Mtoe/year, net potential is 90 Mtoe/year, technical potential is 40 Mtoe/year, economical potential is 25 Mtoe/year, the total available biomass potential is 9 Mtoe/year, and energy potential of forest residue is nearly 6 Mtoe/year (Demirbaş, 2008; Eker et al., 2013).

In Türkiye, the most suitable tree species for the supply of woody biomass for energy purposes (as a rule of thumb) is seen to be Turkish pine (*Pinus brutia* Ten.) (GDF, 2009). Turkish pine has an important share in Türkiye's forest assets and is an ideal tree species for industrial plantations as it is a fast-growing tree species. The product variability obtained from this tree species is also wide range (Table 1) (GDF, 2024). The following results were reailized from studies on the supply of energy wood from logging residues based on this tree species (Eker, 2011).

Table 1. The summary of the distribution of forest trees

| Tree type groups | Hectares | | |
|---|---|---|---|
| | Total | Productive | Degraded |
| Oak (Quercus sp) | 6 833 264 | 2 773 648 | 4 059 616 |
| Turkihs pine (Pinus brutia) | 5 310 854 | 3 578 387 | 1 732 467 |
| Crimaen pine (Pinus nigra) | 4 077 616 | 2 817 266 | 1 260 350 |
| Beech (Fagus orientalis) | 1 904 236 | 1 634 341 | 269 895 |
| Juniper (Juniperus) | 1 551 980 | 445 095 | 1 106 885 |
| Scots pine (Pinus sylvestris) | 1 454 830 | 945 660 | 509 170 |
| Other species | - | - | - |
| Total | 23 245 000 | 13 707 843 | 9 537 157 |

The key drivers for biomass utilization especially for energy purposes in Türkiye are as follows (ReportLinker, 2024):

- Government support (*The Government of Turkish Republic supports policies and incentives for biomass energy production with feed-in tariffs and tax benefits to develop biomass market*)
- Increment on energy demand (*Energy demand is increasing in Türkiye because of population growth, urbanization, and industrialization. These are leading people to use biomass instead of fossil fuels*)
- Renewable energy targets (*The National Renewable Action Plan aims to use of biomass energy within total energy consumption and government supports the bioenergy projects*)
- Availability of biomass feedstock (*The existence of biomass feedstock capacity in Türkiye indicates that this resource can be utilized sustainably*)

Feedstock capacity of logging residues obtaining from *Pinus brutia* Ten. stands, after regeneration felling (clear cutting) (Eker et al., 2013):

- Annual allowable cut is averaged 5 million $m^3$
- The recovery factor is 7–20% green tons per $m^3$ to estimate logging residues
- The technical potential of residues is 700.000 green tons
- Non-merchantable biomass is amount 56 kg/tree in fresh basis
- Non-merchantable biomass is amount 7,5 dry ton/ha
- The recovery rate of non-merchantable biomass is averaged 50 % of the slashes
- The amount of non-merchantable biomass is approximately 350.000 dry ton /year

While the general situation regarding biomass resources that can be used for energy is being outlined, it is necessary to look at what has been done so far in this potential geography. Because in order to understand the system of biomass supply or to investigate the sources of its failure to become systematic, it is necessary to understand what has happened in the last 20 years. Of course, producing energy (steam) from woody biomass for traditional purposes is not something new. However, although there have been many attempts in the past to produce energy (heat and power) with modern techniques, significant developments have been made in the last 20 years.

- ✓ Traditional wood utilization for fuel continues (5.12 M m3 fuel wood; 22% of roundwood)
- ✓ Biomass energy has been a popular agenda in forestry.
- ✓ Industrial plantations, including short rotation energy wood crops, began to become widespread.
- ✓ GDF (General Directorate of Forestry) had started to support forest projects that encourage utilization of forest biomass.
- ✓ The renewable energy law has been renewed (It offers biomass purchase support for energy).
- ✓ Biomass power plants (>100 plants) have begun to be established and become widespread.
- ✓ Research and development on biomass supply and efficient combustion systems have begun to increase.
- ✓ The wood chip industry has increased its capacity as chip trading gained its importance.
- ✓ Pellet production and use has become widespread as an alternative to fossil fuels.
- ✓ Utilization of old stumps and other forest residues for energy become common practices with the increased demand for wood.
- ✓ Fires, unstable wood prices, etc. caused challenges on woody biomass utilization.

On the one hand, energy forestry is being discussed in Türkiye, more than 100 heat and power plants have been established (in 2020, the total installed capacity of biomass production facilities in Türkiye reached 1.485 MW, and the total number of biomass and power and heat production facilities reached 358. The total installed biomass capacity grew by an average of 33.9% annually between 2015 and 2020 (TEIAŞ, 2020)), the increase in the number and capacity of particle board factories, the use of particle board as a commercial product, the production of stump biomass, etc., and many changes have been experienced. On the other hand, research and application projects have been carried out on issues such as how woody biomass should be supplied, which product types can be used for bioenergy, and how maximum utilization can be achieved (Eker et al., 2013).

### 2.1. Biomass Supply Operations in Türkiye

Considering the product distribution and market conditions of woody biomass in Türkiye, it has been thought that logging residues biomass can be a source of raw materials for the energy sector and various studies have been started to be conducted on the establishment of a supply chain in this direction. In the last 15 year, both fiber-chip and bioenergy suppliers who have experienced or are looking for raw materials have started to conduct various experiments on the supply of logging residues. Accordingly, it has been revealed that it would be appropriate to process, remove from the compartment, chip and transport forest residues with the existing (simplistic and mechanized) technology. A typical biomass supply logistics mechanism that has been tried and implemented with simple and intermediate technology options is given in Figure 8.


Figure 8. Residual woody biomass supply possibilities

In the last decade, with the implementation of industrial plantations in managed forests, stump biomass production has become widespread and has turned into a systemic supply chain structure on its own scale (Figure 9) (Eker and Eryılmaz, 2023).

Figure 9. Stump harvesting process

Within the scope of some projects developed in theory and practice, studies on the technical and economic supply of forest biomass in order to use woody material in energy production and to provide sustainable application potential in Türkiye maintain their relevance from time to time at regional and local scales. As it is well-known from the literature (Eker et al., 2013), the important component of the biomass supply system is the chipping process (Figure 10) (Spinelli et al., 2020). Chipping is a key process to provide efficient supply chain logistics. Size reduction through the chipping treatment offers several benefits, such as reduction of bulk density, moisture content, transportation, and storage. The location and time of chipping are also the factors that determine the economics of biomass transport logistics. In Türkiye conditions terrain chipping systems, i.e. chipping inside the field, rarely have the potential for application. However, it has been understood that roadside chipping or at-plant options could be more applicable.

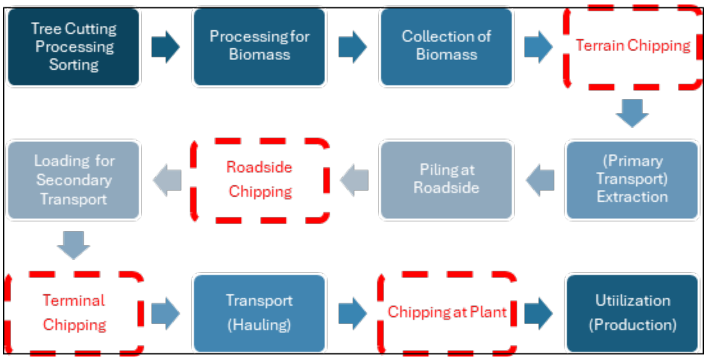


Figure 10. A flow of biomass supply system

**2.2. Key Issues Forest Biomass Utilization in Türkiye**
After the industrial wood harvest operations carried out every year in Turkish forests and the subsequent removal of branch wood to obtain fire (or fuel) wood, logging residues remain at the forest floor as a undesirable materials for forest fire. Large amounts of forest residues are resulting from thinning, tending, and clear-cutting operations. There is a need for removal of the residues from the forest. Keeping harvested woody biomass in the forest is bio-technically and economically disadvantageous.

In Türkiye, the cut-to-length (CTL) harvesting method is generally applied. Therefore, residual biomass harvest operations require a separate process during or after CTL harvesting practices. However, the biomass capacity (recovery rate) per unit forest area is low and is distributed over wide geographical areas. Due to forest laws and policies, forestry operations have to be carried out with the existing labor capacity of forest villagers and by subsidizing them, and this reduces the level of mechanization. As well, terrain conditions of forest lands forces labor intensive operations.

Need for sorting, processing, and quickly transporting for efficient utilization of forest residues. Because of the fire hazard, it is dangerous to store this material in stands. Since residual biomass supply (harvesting and transportation) costs are high, a structured supply system has not yet been established. The demands and purchasing prices offered by the fiber-chip industry sector cause lack of competition and inequality. Therefore, the bioenergy sector, which needs woody biomass, can currently only use stump biomass. However, large fires and market economic conditions prevent the structuring of the biomass supply system. On the other hand, there is lack of more R&D efforts on effective chipping technologies, chip quality, transportation and storage of residual woody biomass.

**3. Mechanical Recovery of Forest Residues in USA**
It is possible to make an assessment to draw various conclusions from American forestry, where mechanical production technologies are applied in woody biomass production from forests. In the USA, biomass harvesting is carried out especially to reduce the amount of combustible material and to renew the generation (Figure 11) (Nicholls et al., 2018). Mechanical biomass harvesting facilitates the tree plantation process after harvesting of timber because it effectively removes forest residues, and the site is ready to plant trees. There have been a wide range of innovative equipment and system logistics developed for biomass supply operations on harvesting/collection, grinding/chipping, and transportation (Halbrook and Han, 2019).

Figure 11. Mechanical collection of residual biomass

In the USA, processed logging residues and small diameter tree trunks that are not classified as industrial wood are used for various purposes (Figure 12).

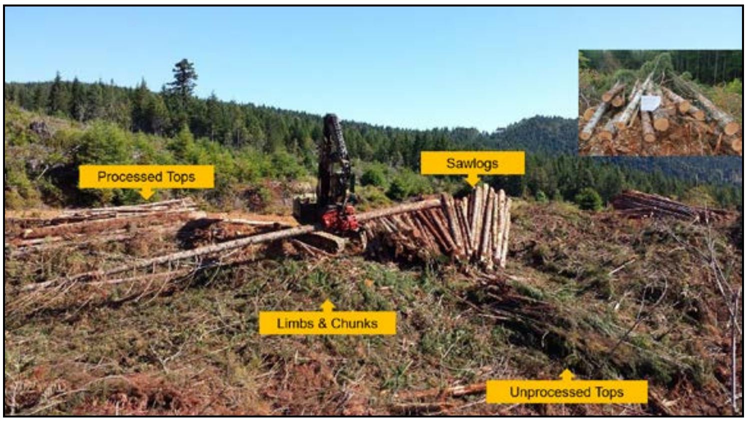



Figure 12. Tree processing and sorting logging residues and small trees

In the implementation in the USA, some strategies are being developed based on reducing the size of biomass and effectively converting into bio-energy or bio-based material in order to benefit from forest biomass. Two of the most important logistic problems encountered in the transportation process have been reported as reducing particle size and moisture content. Because in the production of secondary products to be obtained from biomass (production of biochar, briquettes and refined chips), in order to increase the added value of the product and transport efficiency, the source of biomass should be of high quality and it should be converted (comminuted) close to the forest. Therefore, emphasis is placed on reducing the moisture of woody biomass and reducing the mass (particle) size. For this reason, the particle sizes of woody biomass are reduced by using grinding (for hog fuel) and/or chipping (for wood chips) machines (Figure 13 and 14).

Figure 13. Grinding process for slash (at left) and hog fuel (ground material) (at right)

Figure 14. Chipping for small trees (at left) and wood chips (at right)

It is stated that in order to reduce the moisture content, it would be appropriate to keep the biomass in the stand and/or on the roadside at least until it becomes air dry before reducing the particle size. For this purpose, biomass is ventilated using various piling methods (Figure 15) (Kizha et al., 2017).

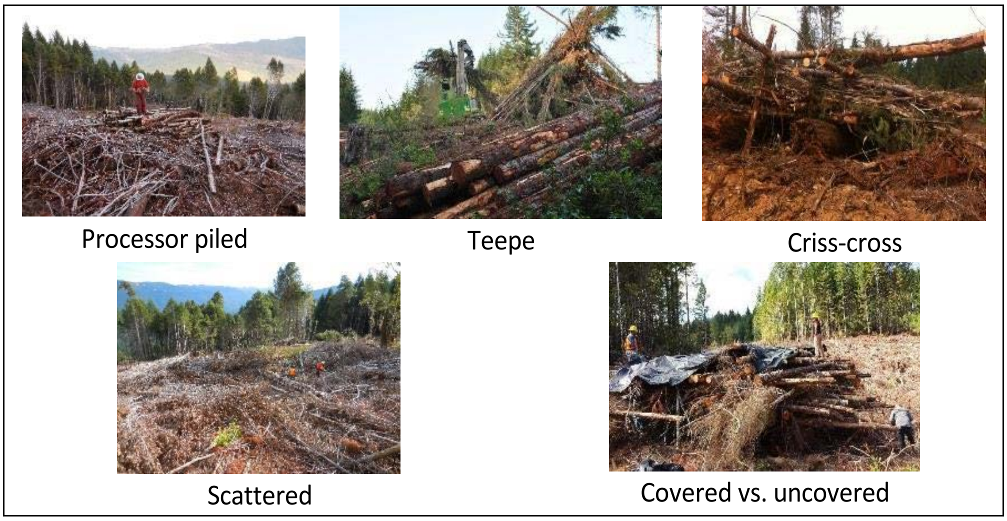



Figure 15. Methods of piling residual biomass to reduce moisture at the stand

In the USA, even if innovative machines are developed and biomass operations are used very efficiently, in addition to reducing biomass sizes, chipping or grinding and transportation costs are usually very high. Because the biomass formed from residues is spread over large areas and there is low biomass efficiency in the unit areas. In this case, transportation vehicles need to travel very frequently and long distances to collect all the biomass in the areas. This increases transportation costs. In addition, the long time spent on chipping operations in the compartment or on the roadside causes transportation vehicles to wait idle and the trucks developed for the transportation of chips need a wide curve radius on forest roads. On the other hand, markets pay very low price for these feedstocks. So, the utilization of forest residues for energy is often economically not feasible.

Whole trees, logging slash, and bundles are hauled to a concentration yard using small trucks which can travel forest roads with poor travel conditions. Once there is enough material compiled at the concentration yard, a grinder or chipper can be employed to process and haul them to energy plant. This approach allows effective access to forest residues piled in remote areas and high levels of machine utilization for each machine involved. In terms of finding innovative options, logistics centralized biomass operations (Figure 16) can offer several advantages (Han et al., 2018). Such that:

- Improved access to scattered residue piles,
- Less machine downtime (Less time for equipment to move between piles; Less wait time for biomass),
- Flexible scheduling through "decoupling" harvesting phases,
- Opportunity for extending harvesting season and
- Additional drying at central landings.

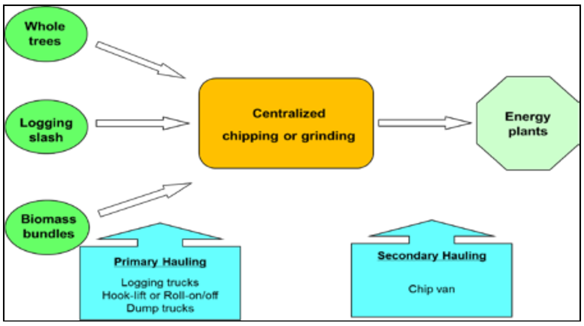



Figure 16. Conceptual framework of centralized biomass operations

Various technologies have been developed in the USA to both reduce costs and overcome transport logistics problems, and alternative supply systems are being proposed and tested accordingly. Development of these harvest and transport technologies, in other words, increasing of mechanization level can improve access to forest residues, improve machine utilization rates, facilitate operational management, and help reduce harvest/transportation costs (Han et al., 2010). Some supply operation technologies are given in following figures (Figure 17, 18, and 19) as an example for developing countries like Türkiye.

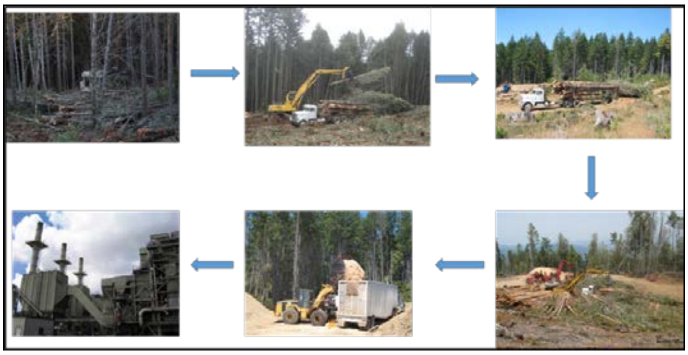


Figure 17. Integrated harvesting of biomass in centralized chipping

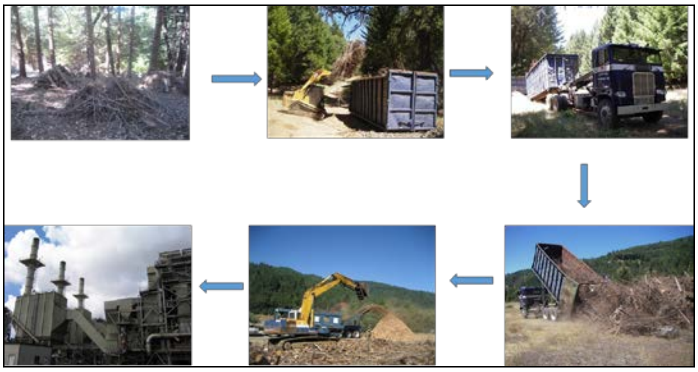


Figure 18. Roll-off container trucks in a centralized grinding operation

Figure 19. Alternative method: Dump truck in centralized chipping

## 4. Discussion and Suggestions

The problems encountered in the supply of woody biomass for energy or other bio-products in Turkish forestry have been summarized in general. When the solutions suggested for such basic problems in the biomass supply system in the USA are taken into consideration, the following judgments can be reached for Türkiye and the following suggestions can be made as well:

- ✓ To shorten the procurement process and avoid entering the same stand second time, separating industrial roundwood (most valuable commercial wood) from forest residues during the wood harvest operation can increase the efficiency of residual supply possibilities and the chipper productivity, and reduce costs.
- ✓ Moisture content can be reduced to less than 20% on site by allowing an increased amount of air flow in the wood piles.
- ✓ Operational efficiency can be significantly enhanced by using biomass machines and trucks that are specially designed for handling biomass materials.
- ✓ Improved logistics of biomass operations are effective in reducing operational costs.
- ✓ Advancement in biomass conversion technologies is needed to improve economic feasibility of biomass utilization.
- ✓ Through chipping of forest residues, we can produce various types (wood chips, micro-chips, and sawdust) of feedstock uniform in size by supporting of screening machines.

## References

Demirbaş, A. 2008. Importance Of Biomass Energy Sources for Turkey. Energy Policy. 36(2): 834–842.

Eker, M. 2011. Assessment of Procurement Systems for Unutilized Logging Residues for Brutian Pine Forest of Turkey. African Journal of Biotechnology. 10(13): 2455-2468.

Eker, M. 2014. Trends in Woody Biomass Utilization in Turkish Forestry. Croatian Journal of Forest Engineering. 35(2): 288-270.

Eker, M., Acar, H., Özçelik, R., Alkan, H., Gürlevik, N., Çoban, H. O., Korkmaz, M., Yılmaztürk, A. 2013. Investigation on Supply Possibilities of Logging Residues in Forestry – Final Report (In Turkish). TUBITAK. Project No:110O435, Ankara.

Eker, M., Eryılmaz, A. 2023. Stump Harvesting Methods in Turkish Forestry. B.N. Rashid (Ed.), Strategic Research in the Field of Sustainability-Based Agriculture and Forestry. Klaipeda: SRA Academic Publishing. 25-62 p.

GDF, 2009. Existing Studies on Bioenergy in General Directorate of Forestry. Bioenergy Working Group, General Directorate of Forestry. www.ogm.gov.tr

GDF, 2024. Forestry Statistics 2023. Offical Statistics. https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler (Accessed 10 September 2024)

Halbrook, J., Han, H. S. 2019. Chip & Ship: Testing the Logistics of Supplying Wood Chips Over Long Distances Using Intermodal Railroad Transportation. ERI Technical Report. Ecological Restoration Institute, Northern Arizona University. 30 pp.

Han, H. S., Halbrook, J., Pan, F., Salazar, L. 2010. Economic Evaluation of A Roll-Off Trucking System Removing Forest Biomass Resulting From Shaded Fuelbreak Treatments. Biomass & Bioenergy Journal. 34:1006-1016.

Han, H. S., Jacobson, A., Bilek, E. M., Sessions, J. 2018. Waste to Wisdom: Utilizing Forest Residues for The Production of Bioenergy and Biobased Products. Applied Engineering in Agriculture. 34(1): 5-10.

Kizha, A. R., Han, H. S., Paulson, J., Koirala, A. 2017. Strategies for Reducing Moisture Content In Forest Residues At The Harvest Site. Applied Engineering in Agriculture. 34(1): 25-33.

Klavins, L. Almonaityte, K., Šalaševiciene, A., Zommere, A., Spalvis, K., Vincevica-Gaile, Z., Korpinen, R., Klavins, M. 2023. Strategy of Coniferous Needle Biorefinery into Value-Added Products to Implement Circular Bioeconomy Concepts in Forestry Side Stream Utilization. Molecules. 28: 7085.

Nicholls, D. L., Halbrook, J. M., Benedum, M. E., Han, H. S., Lowell, E. C., Becker, D. R., Barbour, R. J. 2018. Socioeconomic Constraints to Biomass Removal from Forest Lands for Fire Risk Reduction in The Western U.S. Forests. 9(264): 1-22.

Report Linker, 2024. Biomass Market Size 2024. https://www.reportlinker.com/market-report/Bioenergy/ (Accessed 12 October 2024)

Röser, D., Asikainen, A., Rasmussen, K. R., Stupak, I. 2008. Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on The Baltic and Nordic Countries. Managing Forest Ecosystems. 2:232.

Spinelli, R., Eliasson, L., Han, H. S. 2020. A Critical Review of Comminution Technology and Operational Logistics of Wood Chips. Current Forestry Reports. 10p.

Strykowski, W. 2013. Wood – a Substitute or A Raw Material Substituted For. Annals of Warsaw University of Life Sciences - SGGW Forestry and Wood Technology. 84:194-200.

TEİAŞ, 2020. Kurulu Güç Raporu Aralık 2020. Yük Tevzi Dairesi Başkanlığı. https://www.teias.gov.tr/kurulu-guc-rapo

# An Assessment on the Methods of Unit Price Calculation Procedure for Wood Harvesting

**Mehmet Eker[1*], Selami Cilan[2], Natascia Maganotti[3], Hakan Durgun[1]**

[1] Isparta University of Applied Sciences Faculty of Forestry, Isparta, Türkiye
[2] Ministry of Agric. and Forestry, General Direct. of Forestry, Dept.of Business and Marketing, Ankara, Türkiye
[3] Institute of BioEconomy, The National Research Council, Sesto Fiorentino - Italy
*mehmeteker@isparta.edu.tr

## Abstract

The aim of this study is to criticize the methodology followed to develop the method of calculating harvesting unit prices in Türkiye (TR), which is in the transition period to mechanization in wood harvest operations, in terms of the principles stated in the good practice guidelines. The main issue here is to evaluate the principles on which the method followed is based on how to calculate the cost of production (harvest and transportation) of 1 $m^3$ of wood raw material in the most realistic way and to the satisfaction of the stakeholders. The unit price method is a function of the unit costs of labor and/or machine power used for the harvest operations and the standard time consumed per unit wood. Because cyclical changes in labor and machine energy inputs used during wood supply chain can cause significant problems in cost calculation and price creation. For example, in Turkish forestry managed by state-run forestry, the unit price calculation method is used for all kinds of wood harvesting and various changes have been observed over time depending on technological developments. Since the increase in mechanization opportunities and technological diversity due to road density, increase in purchasing and investment power, changes both unit costs and standard working hours, there are also updates in determining unit prices. For this calculation method, inputs and outputs in wood harvest operations are measured according to scientific principles, standard working times of various operation techniques are determined, and production unit prices per unit amount of product can be calculated by treating them with flexibly determined unit costs. It is seen that this method, which has been followed in recent years, and the methodology followed during its development have not been evaluated from various aspects. In this study, the background of the unit price calculation method developed for TR forestry by following the good practice guideline prepared for woody biomass production at the worldwide was evaluated from various aspects.

***Keywords:*** *Wood harvesting, unit price, time input, cost calculation, good practice guideline*

## 1. Introduction

Wood raw material production is a leading component of economic oriented functions for forestry. One of the sole goals throughout the process of utilizing forest products is to minimize the operational costs of wood raw material procurement from forest resources for producers and consumers. In order to determine the sales price of wood raw material obtained from forests owned by the state or private entities, it is necessary to know the actual costs. The unit price method is a function of the unit costs of labor and/or machine power used for the harvest operations and the standard time consumed per unit wood (Yıldırım, 1989; Erdaş et al., 2014; Acar and Eroğlu, 2016).

Harvesting costing acts a key role in planning, controlling, and execution of harvesting operations. It is the key factor of all production processes of enterprises, Therefore harvest costing is one of the most significant problems for forest companies, depends on highly qualified personnel and a well-organized system of planning, implementing, and controlling. Harvest costing is also very complex, because many burden centres have to be considered in cost calculation. Machines and equipment used in harvesting operations in general are costly, specifically if high volumes of wood assortments have to be produced or heavy stems have to be manipulated. For cost calculation procedure of harvest system, a series of information are also necessary. Operational conditions of a forest stands have to be known, since they determine the use of the appropriate equipment and its productivity. The forest type (planted or native), tree dimension, terrain conditions, soil properties, and wood utilization have to be considered for decision making and cost calculation. If the technology that match with all requirements are determined, the respective costs of the system may be estimated (Malinovski et al., 2016).

Because cyclical changes in labor and machine energy inputs used during wood supply chain can cause significant problems in cost calculation and price creation. For example, in Turkish forestry managed by state-run forestry, the unit price calculation method is used for all kinds of wood harvesting and various changes have been observed over time depending on technological developments (Şafak et al., 2019). Since the increase in mechanization opportunities and technological diversity due to road density, increase in purchasing and investment power, changes both unit costs and standard working hours, there are also updates in determining unit prices.

The aim of this study is to criticize the methodology followed to develop the method of calculating harvesting unit prices in Türkiye (TR), which is in the transition period to mechanization in wood harvest operations, in terms of the principles stated in the good practice guidelines (GPG). This study covers examining whether the unit price calculation method currently used to obtain 1 $m^3$ of wood raw material complies with international standards and revealing what changes have occurred in the unit price determination method due to the increasing tendency for harvest mechanization. The unit price discussed in this study refers to the fee paid for obtaining a unit amount of product (1 $m^3$ of wood), which is the result of multiplying the unit cost by the unit time (Unit price = Unit costs x Unit time).

In order to conduct the study, legislation related to the unit price calculation in the last 40 years, the current legislation structure and international GPG were examined. In this paper, after the general structure of Turkish forestry was introduced, the chronology of the legislation was given and the unit price calculation method was introduced and criticized from various perspectives with GPG.

## 2. Forest and Forestry in Türkiye

### 2.1. Forest Resources

In order to understand the calculation method of unit price, it would be useful to present some metrics about the conditions under which commercial wood production is carried out in TR forestry. Accordingly; TR's total forest area is 23,4 million hectares. 57% of this forest area is productive high forests. The total growing stock of forest areas is over 1,7 billion cubic meters. The annual current increment is approximately 50 million cubic meters. On the other hand, approximately 50% of TR’s forest areas are reserved for ecological functions and slightly more than 40% are managed with economic functions.

### 2.2. Forest Administration and Management

TR's forests are managed in accordance with the hierarchy of norms as respectively; constitution, forest law, forest regulations, forestry policy, international conventions, national forestry strategic plans, forestry master plans, forestry programs, regional and local action plans, and forest management plans. The majority (over 99%) of forest land is state owned and managed forest. The forestry legislation dictates that forest villages and their villagers be subsidized (for example, supporting the outsourcing of all forestry operations to forest villagers). About 10 percent of Türkiye's population (about 7 millions) lives in forest or forest-neighbouring villages. A total of 141.000 villagers, half of which are member of forest cooperatives, have been employed in forest operations, and 42.000 personnel have been employed in the state forest administrations. The life standards of these communities are quite lower than the country's average (GDF, 2024).

The administration and management of all forests are executed by General Directorate of Forestry (GDF) of the Ministry of Agriculture and Forestry (MAF). GDF is administratively divided into regional directorate of forestry. This spatial division continues from the regional directorate to the chief of forest district, depending on administrative and geographical characteristics. There are 30 regional directorates, 277 forest district, and 2147 chief of forest district as a planning unit (that is called as forest enterprise). The average area size of chief of forest district varies between 5.000-15.000 hectares. Decision making and forest operations have been planned, organized, guided, managed, and controlled through the Chief Office of the Forest District (COFD), as respectively and hierarchically.

### 2.3. Forest Products

The amount of annual allowable cut from state-owned TR's forests is nearly 25 million cubic meters, according to the last 5 years of average data (Figure 1). When we look at the distribution of roundwood products, it can be ranged from the fibre-chip wood (40%; the timber log (37%), pulpwood (16 %), the others (7%), and fuel wood as respectively (Table 1) (GDF, 2024).

The forestry sector, which has an economic size of 25 billion dollars and exports of 8 billion dollars in 2023. About 70% of TR's wood supply is provided by state-owned forestry while the others is given by the private sector and import.

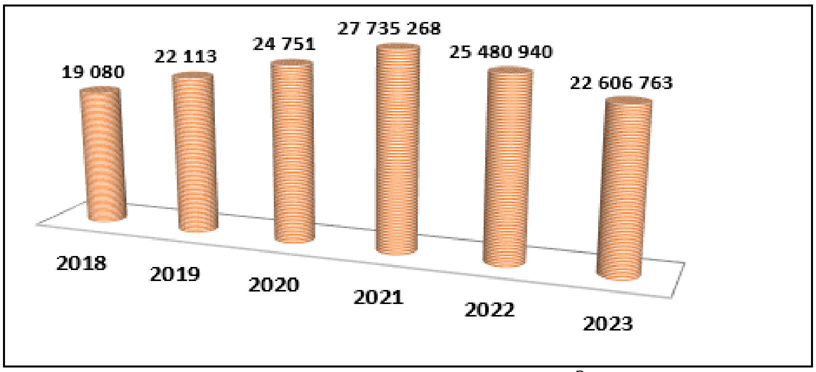



Figure 1. Industrial roundwood production (as $m^3$) between 2018-2023

Table 1. Product range of 2022 year in Turkish forestry

| Woody Products | Quantity (m³) |
|---|---|
| Industrial Roundwood | 22 606 763 |
| Coniferous wood | 15 999 531 |
| *Log* | *6 651 737* |
| Telephone pole | 76 418 |
| Mining pole | 815 150 |
| Other industrial wood | 501 446 |
| Pulpwood | 2 958 628 |
| Fibre-chip wood | 4 987 952 |
| Thin pole | 8 200 |
| Non-coniferous wood | 6 607 2232 |
| *Log* | *1 624 894* |
| Mining pole | 61 235 |
| Other ındustrial wood | 368 306 |
| Pulpwood | 558 348 |
| Fibre-chip wood | 3 994 199 |
| Thin pole | 250 |
| Fuel wood | 5 166 656 |
| Fuel wood (coniferous) | 2 067 564 |
| Fuel wood (non-coniferous) | 3 099 082 |

### 2.4. Wood Harvest Operations

Harvesting rate is based on the management and silviculture plans. Roundwoods are supplied by thinning, tending and final cutting. Forest villagers have to be worked by law for harvest operations. Forest villagers prefer labor-intensive physical working (Figure 2a). Basic technologies are preferred due to higher machine fixed and operational expenses (Low yield capacity per ha for compansation of machine costs) (Figure 2b). Social security and health insurance of harvests workers are paid by themselves.


Figure 2. (a) Manually ground skidding (at left) and (b) basic technology (at right)

The wood harvesting process consists of cutting, extraction, loading, transportation and stacking operations in state-owned storages. When 1 $m^3$ of wood is desired to be supplied, this work phase (sub-process) of the harvesting process is exceeded. Therefore, the supply cost of 1 $m^3$ of wood depends on the costs of the components of the harvesting system. During the harvest operations; manpower, machine power and animal power can be used with together (Figure 3). Since the technology used in each process and each work step is different, the cost of each which is determined separately.


Figure 3. Process & system boundary for wood harvesting in TR

## 3. Harvesting Cost and Unit Price Calculation

When the calculation method of the unit price to obtain 1 cubic meter of product in the production of wood raw materials is examined, it is seen that the unit price is a function of unit cost and standard time. The price or cost per unit product quantity is determined by multiplying the hourly working cost by the time spent to supply 1 $m^3$ of wood. The unit price is the equivalent of procurement 1 $m^3$ of wood in each work item to be done (Equation 1).

$$\text{Unit Price (TL/m}^3\text{)} = \text{Unit Cost (TL/hour)} \times \text{Unit (Standard) Time (hour/m}^3\text{)} \quad (1)$$

This payment means the "unit price of the work per piece work" in general. If the producer, that is, the state-owned forest enterprise, is considered, this payment for the unit price is called "cost". In other words, it is the "actual cost" paid by the forest enterprise for logging and transportation 1 $m^3$ of wood. If the employee or the logger who will do the job is concerned, this value is the amount to be paid for the job, that is, the "price for doing work". It is the amount of money that the employee will earn in return for spending his own energy or machine or animal power in return for obtaining 1 $m^3$ of wood.

Unit price calculation is made based on the actual hierarchy of norms as follows;

- The constitution of TR
- Forest law (No: 6831)
- Regulation (Regulation on Harvesting of Forest Products, No:19231)
- Rescript (Rescript on The Harvesting of Wood-Based Forest Products)

- Rescript on Harvesting of Forest Products, No:161-A (1982-1996)
- Rescript on Harvesting of Primary Forest Products, No:288 (1996-2019)
- Rescript on The Harvesting of Wood-Based Forest Products, No:310 (2020 - …)

The unit price is calculated by Chief of Forest District before the harvest operations using a software commonly used nationwide, according to the characteristics of the stand based (site-specific) parameters. The unit price is calculated separately for each forest district, each compartment/stand, and each operation (cutting, extraction, loading, hauling, stacking) (Figure 4).


Figure 4. Operation techniques for unit costing

### 3.1. Unit Costs for Harvesting

The unit cost values required for the unit price are determined by the General Directorate of Forestry, which is the center of the forestry organization in Ankara, at the beginning of each fiscal year and reported to all provincial organizations (regional directorate of forestry). In other words, the hourly unit costs of the worker and/or machine are centrally determined. Separate unit costs are calculated for the first and second part of the year. Separate costs are also determined for each operation, i.e. work step, in the harvesting activities (Table 2). Unit cost for workers (operators/loggers) is determined according to the daily wage corresponding to the monthly minimum living conditions, taking into account the nature of the work and the difficulty of the work for the workers. Fixed and variable costs are taken as basis in determining the unit costs of work machines.

Table 2. Hourly unit costs of worker and harvest operation technology for 2024 year

| Production Sector | Unit Cost Type | Unit Costs (TL/hour) | Valid Date | Unit Costs (TL/hour) | Valid Date |
|---|---|---|---|---|---|
| Cutting | MUC* | 238.95 | 01.01.2024 | 274.8 | 01.07.2024 |
| | LUC** | 166.74 | 01.01.2024 | 191.76 | 01.07.2024 |
| Extraction | MUC | 646.32 | 01.01.2024 | 743.28 | 01.07.2024 |
| | LUC | 333.48 | 01.01.2024 | 383.52 | 01.07.2024 |
| Loading | MUC | 424.68 | 01.01.2024 | 488.37 | 01.07.2024 |
| | LUC | 500.22 | 01.01.2024 | 575.28 | 01.07.2024 |
| Hauling | MUC | 1672.89 | 01.01.2024 | 1923.81 | 01.07.2024 |
| | LUC1 | 166.74 | 01.01.2024 | 191.76 | 01.07.2024 |
| | LUC2 | 333.48 | 01.01.2024 | 383.52 | 01.07.2024 |
| Stacking | MUC | 487.05 | 01.01.2024 | 657.51 | 01.07.2024 |
| | LUC | 333.48 | 01.01.2024 | 383.52 | 01.07.2024 |
| Total | | 5304.03 | | 6197.13 | |
| 1€=35 TL | | 151.5€/hour | | | |

The well-known cost modelling method is used in calculation the unit costs of machines (Table 3). For example, when the average exchange rate of 2024 is taken into account; the hourly total cost of cutting, extraction, loading, hauling and stacking (i.e. when 1 hour is consumed for each operation) corresponds to approximately 151.5 euros/hour. This figure is reached when it is assumed that both people and machines are operated together. However, since the amount of product obtained in each operation is not known, it would not be correct to estimate the costs for 1 $m^3$ of product with the help of these costs. In this case, the most important component of the equation is the working time data that will be used to determine the work efficiency. So, unit cost value is almost a constant coefficient.

Table 3. Machine (rate) costing model

| Machine description | Farm Tractor | Chipper | Forest Tractor | Truck | Tractor Trailer | Loader |
|---|---|---|---|---|---|---|
| 1. Input Data | | | | | | |
| Purchase price ($) | 40000 | 60000 | 90000 | 100000 | 4000 | 85000 |
| Machine Horsepower rating (hp) | 50 | 85 | 95 | 240 | - | 95 |
| Machine life (years) | 10 | 5 | 10 | 10 | 5 | 10 |
| Utilization rate (%) | 70% | 70% | 70% | 100% | 50% | 65% |
| Fuel consumption rate (gal/hp-PMH) | 0.022 | 0.026 | 0.029 | 0.04 | - | 0.026 |
| Scheduled machine hours (SMH/year) | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 |
| 2. Calculations | | | | | | |
| Average yearly investment ($) | 25600 | 40800 | 57600 | 68500 | 2720 | 58225 |
| Productive Machine Hours (PMH/year) | 1400 | 1400 | 1400 | 2000 | 1000 | 1300 |
| 3. Ownership costs | | | | | | |
| Yearly ownership cost ($/year) | 6528 | 14904 | 14688 | 15905 | 994 | 14684 |
| Ownership cost ($/SMH) | 3.26 | 7.45 | 7.34 | 7.95 | 0.5 | 7.34 |
| Ownership cost ($/PMH) | 4.66 | 10.65 | 10.49 | 7.95 | 0.99 | 11.3 |
| 4. Operating costs | | | | | | |
| Fuel cost ($/ph) | 11 | 22.1 | 27.55 | 96 | - | 19.76 |
| Lube cost ($/ph) | 4.07 | 8.18 | 10.19 | 9.6 | - | 7.31 |
| Repair and maintenance cost ($/PMH) | 2.06 | 6.17 | 4.63 | 3.5 | 0.64 | 4.12 |
| Operator labor and benefit cost ($/PMH) | 8.57 | 8.57 | 8.57 | 6 | - | 9.23 |
| Operating cost ($/SMH) | 17.99 | 31.51 | 35.66 | 115.1 | 0.32 | 26.27 |
| Operating cost ($/PMH) | 25.7 | 45.02 | 50.94 | 115.1 | 0.64 | 40.42 |
| 5. Total Costs | | | | | | |
| Total cost ($/SMH) | 21.25 | 38.97 | 43 | 123.05 | 0.82 | 33.62 |
| Total cost ($/PMH) | 30.36 | 55.67 | 61.43 | 123.05 | 1.63 | 51.72 |
| Worker (4 person) $/PMH | - | 10 | - | - | - | - |
| Available Total Cost ($/PMH) | 30.36 | 65.67 | 61.43 | 123.05 | 1.63 | 51.72 |
| Machine Rental Cost $/PMH | 31.81 | - | 63.41 | 123.8 | - | 53.71 |

### 3.2. Unit (Standard) Time

The most important component required for calculating unit price is standard or unit time. In work study terminology, standard time is the working time of a human or machine (or animal) required to perform a job under normal conditions. It is a unit time for an operation. It is developed to address payment inequality based on differences in regional and local conditions.

In the case of a worker or a machine, the time components that constitute standard time may differ. In order to standardize worker working time, the sum of the times related to work-related or non-work-related activities in the workplace, such as productive working time, additional activity time, distribution time and rest time, is taken as basis. Unit time means for a worker; the time required for qualified workers who have adopted their jobs and used the right methods to do a job with a natural working tempo and standard performance. It can be called "workplace time" or "scheduled time" (includes work and non-work time). Unit time means for a machine; it is the machine operating time or machine utilization time or work time required for the job done. The amount of time a machine must operate to produce the amount of output under optimal operating conditions. It can be called "scheduled machine hour" or "work time" (not includes non-work time; disturbance and delay time). For machines, unit or standard working time consists of the sum of productive working time and supporting or additional working times (Magagnotti and Spinelli, 2012). In other words, it is obtained by measuring only the working time of the machine and the objective distribution times required for the operation of the machine.

Unit working hours are determined centrally by the GDF and are implemented in all state forest enterprises with a legislation, that is, an application guide. GDF centrally determines fixed (constant) coefficient, through Rescprit No.310. This enables the calculation of similar unit prices all over Türkiye under similar conditions. Calculation procedure for unit time was changed 3 times during last 40 years. State forestry research stations had completed 3 scientific projects between 2015-2018 years for time analysis in order to provide standard time values could be supplied for wood harvesting. In order to collect the precise data, time and motion studies were conducted by working with a team of 30-50 selected and well-trained forest engineers as a surveyor. By means of the projects, sufficient data has been collected for all operations related to the harvesting process in different regions and different tree species. Data obtained from both experimental and observational design established by taking into account tree species, land structure, slope, technology used, stand characteristics, operation types, worker characteristics, etc. variants were used.

Unit time calculated separately depends on the site-specific conditions and for each operation (such as cutting, extraction, loading, hauling, and stacking), for each stand, for workers, for each machine type. Factors changing the standard time value:

- Season (Summer and winter conditions for representing climate variations),
- Terrain conditions (Slope and skidding distance),
- Tree types (coniferous and broadleaves),
- Machine or technology diversity,
- Stand parameters,
- Distances,
- Road standards, etc.

For example, in the current legislation (Rescript No: 310), the standard time for a cutting/felling operation is estimated based on the working time required to cut down (felling) the tree, delimbing, bucking and debarking (There is the debarking of round wood with a middle diameter larger than 13 cm, in the stand for conifers). Standard times are separately determined for both humans and machines works. The standard time for the cutting is determined according to the dbh and the terrain slope class. Other variations based on effective factors were implicitly added to the time value as distribution time. The standard times are given as table values and are seen on the table in decimal minutes (Table 4).

Table 4. The calculation base for standard time of tree felling (GDF, 2019)

| Dbh | Slope class (%) | | | | | | | | Dbh | Slope class (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-30 | | 31-60 | | 61-100 | | >100 | | | 0-30 | | 31-60 | | 61-100 | | >100 | |
| | LUT | MUT | LUT | MUT | LUT | MUT | LUT | MUT | | LUT | MUT | LUT | MUT | LUT | MUT | LUT | MUT |
| 8 | 81.63 | 31.72 | 101.67 | 47.46 | 110.98 | 54.78 | 133.76 | 72.64 | 55 | 15.28 | 11.14 | 15.91 | 11.64 | 18.72 | 13.86 | 23.43 | 17.55 |
| 9 | 59.47 | 25.68 | 74.26 | 37.29 | 81.85 | 43.26 | 100.93 | 58.24 | 56 | 15.23 | 11.12 | 15.82 | 11.6 | 18.65 | 13.82 | 23.31 | 17.48 |
| 10 | 50.18 | 23.67 | 62.43 | 33.29 | 69.06 | 38.5 | 85.12 | 51.11 | 57 | 15.2 | 11.12 | 15.73 | 11.59 | 18.59 | 13.79 | 23.22 | 17.42 |
| 11 | 42.27 | 21.4 | 52.59 | 29.5 | 57.9 | 33.67 | 71.4 | 44.25 | 58 | 15.17 | 11.12 | 15.66 | 11.59 | 18.53 | 13.76 | 23.11 | 17.37 |
| 12 | 38.68 | 20.72 | 47.79 | 27.88 | 52.84 | 31.84 | 65.22 | 41.55 | 59 | 15.12 | 11.1 | 15.56 | 11.59 | 18.45 | 13.72 | 23 | 17.3 |
| 13 | 36.43 | 20.46 | 44.56 | 26.84 | 49.39 | 30.64 | 60.72 | 39.52 | 60 | 15.1 | 11.1 | 15.56 | 11.59 | 18.39 | 13.69 | 22.91 | 17.25 |
| 14 | 34.45 | 19.91 | 41.82 | 25.68 | 46.37 | 29.26 | 57.56 | 38.03 | 61 | 15.07 | 11.1 | 15.56 | 11.57 | 18.34 | 13.67 | 22.82 | 17.19 |
| 15 | 31.84 | 18.85 | 38.19 | 23.84 | 42.48 | 27.2 | 53.19 | 35.6 | 62 | 15.05 | 11.1 | 15.56 | 11.55 | 18.29 | 13.63 | 22.75 | 17.16 |
| 16 | 30.49 | 18.42 | 36.17 | 22.89 | 40.17 | 26.03 | 50.71 | 34.29 | 63 | 15.02 | 11.1 | 15.56 | 11.53 | 18.23 | 13.62 | 22.7 | 17.1 |
| 17 | 29.9 | 17.9 | 35.04 | 21.94 | 38.79 | 24.87 | 49.18 | 33.03 | 64 | 15 | 11.1 | 15.53 | 11.51 | 18.18 | 13.59 | 22.58 | 17.05 |
| 18 | 29.1 | 17.44 | 33.57 | 20.95 | 37.21 | 23.79 | 47.38 | 31.78 | 65 | 14.98 | 11.1 | 15.49 | 11.49 | 18.14 | 13.57 | 22.51 | 17.01 |
| 19 | 28.69 | 16.57 | 32.62 | 19.66 | 35.99 | 22.3 | 45.74 | 29.95 | 66 | 14.96 | 11.1 | 15.46 | 11.48 | 18.1 | 13.55 | 22.39 | 16.92 |
| 20 | 28.28 | 16.1 | 31.76 | 18.84 | 34.99 | 21.37 | 44.48 | 28.82 | 67 | 14.95 | 11.1 | 15.42 | 11.46 | 18.06 | 13.53 | 22.19 | 16.78 |
| 21 | 27.49 | 15.66 | 30.45 | 17.98 | 33.38 | 20.29 | 42.93 | 27.77 | 68 | 14.93 | 11.1 | 15.39 | 11.44 | 18.02 | 13.51 | 22.01 | 16.65 |
| 22 | 26.26 | 15.31 | 29 | 17.46 | 31.87 | 19.71 | 41.13 | 26.99 | 69 | 14.92 | 11.1 | 15.36 | 11.43 | 17.98 | 13.49 | 21.83 | 16.53 |

LUT: Labor unit time; MUT: Machine unit time

In the same legislation, regression equations or coefficients have been produced and used according to different techniques and technologies for extraction, loading and hauling unit times. Regression equations for unit time estimation were created for roundwood extraction (from stump to roadside), which depends on tree types, transportation direction (up, down), terrain/route slope, extraction (skidding) distance, and logging system type. An example the content is shown in Table 5 below.

Table 5. Example of tractor cable logging upwards

| | | |
|---|---|---|
| Broadleaves | Labor unit time | $t_e$ = 8,9150+0,1319.s+0,0485.e |
| | Machine unit time | $t_e$ = 7,4383+0,1086.s+0,0399.e |
| Coniferous | Labor unit time | $t_e$ = 8,2567+0,1251.s+0,0098.e |
| | Machine unit time | $t_e$ = 6,8962+0,1030.s+0,0081.e |

$t_e$: Labor unit time or Machine unit time; s: cable length (m); e: route slope (%)

A constant coefficient is used over the table value for loading (at the roadside). It is assumed that humans and machines work together. The unit time was determined by using of various types of loaders. To determine the unit time; the action distance of the loader, the volume of the log, the number of pieces, the capacity of the truck, etc. were taken into account. An example can be shown in Table 6.

Table 6. Loading unit time for 1 $m^3$ of log (1/100 decimal minute)

| Type | Labor unit time | Machine unit time |
|---|---|---|
| Broadleaves | 5.58 | 2.93 |
| Coniferous | 5.94 | 3.21 |

Regression equations were also developed for hauling operations (from roadside to storage). In determining the unit time of truck transportation, the following components are implicitly taken into account, such as; the feature of the road (asphalt, stabilized, raw road), the length of the roads, the adverse slope, the features of the trucks, the empty departure and full return times (Table 7).

Table 7. Example of hauling unit times for 3 different road types

| | |
|---|---|
| Labor unit time | $t_e = 5{,}3730+0{,}1340.Ay+0{,}2620.Sy+0{,}7100.Hy$ |
| Machine unit time | $t_e = 4{,}6640+0{,}1160.Ay+0{,}2270.Sy+0{,}6130.Hy$ |

$t_e$:Labor unit time or Machine unit time; Ay: asphalt road length (km); Sy: stabilized road length (km), Hy: raw road length (km)

## 4. Discussion and Result

When the Rescript (Communiqué) No. 310, which was developed to calculate harvesting costs and therefore production unit prices and is a legal regulation, is examined and compared with the GPG contents in the literature, it can be highlighted that the following judgments and conclusions are reached: These are;

- ✓ The legislation at the rescript level has the capacity of GPG for harvesting costing procedure in TR.
- ✓ The rescript is explanatory on the procedures on unit price calculation. This shows similarity with the GPG.
- ✓ The unit price calculation procedure is indexed to 1 $m^3$ of industrial round wood. Depending on tree species, market conditions (conjuncture), sales method and customer profile, sometimes «ton» units may be used. Then, the unit price calculation procedure may show inconsistency.
- ✓ The fact that the centrally determination on unit costs cannot be understood by managers, customers and workers (loggers). This shows that this system is a black box decision making process. Unit cost rate is not suitable for adaptation to local conditions.
- ✓ The separate calculation procedure of unit prices for cutting, extraction, loading, hauling and stacking operations indicates the sensitivity of the methodology for the wood harvesting system.
- ✓ Rescript No:310 is competent in presenting how to calculate standard (unit) times, which is the most dynamic component of the unit price equation. Managers, loggers, customers and workers can see and understand this part of the procedure.
- ✓ The machine rate cost model used in the calculation of unit costs is similar with well-known GPGs.

- ✓ The sensitivity of unit price calculation procedure to changes, overlaps with the cost calculation procedures in the literature.
- ✓ In the last 3 rescripts, there is no detail about what the standard times include and how they are determined. However, when similar GPGs are examined, it is thought that this is not necessary.
- ✓ While the workplace time is taken as the basis in determining the standard labour work time, SMH is taken as the basis in determining the human controlled machine standard time. This is compatible with GPGs.
- ✓ Although static table data is used as input for cutting times, regression equations sensitive to variable factors are used for the estimation of the extraction standard times. It can be said that extraction unit prices are obtained with a semi-dynamic calculation procedure.
- ✓ Although the evolution towards the use of mechanized systems is observed in TR, the unit cost and standard working time equations have been developed by taking into account the basic technology with labour force. This shows that the current procedure provides subsidies to forest villagers.
- ✓ While the number of factors affecting unit time was quite high in previous rescripts (No.161-A and 288), the number of factors (season, altitude, tree species, difficulty coefficient, etc.) has been not directly included in the latest rescript (No.310). However, the effects of the factors have been implicitly added to the standard time as a total share. This indicates that a practical calculation procedure is aimed.

The consistency of the unit price estimation made before harvest operations depends on the correct calculation of the standard time. For this, data such as tree diameter, product range, land slope, skidding distance, road length, etc. which will be used to determine human and machine working time, should be supplied as input at the operational inventory level with the precision forestry approach. New tables or equivalents for machine standard times should be developed for newly operated machines in TR (cable lines, cranes, skidders, harvesters, forwarders, etc.).

**References**

Acar, H. H., Eroğlu, H. 2016. Ormancılık İş Bilgisi ve İş Güvenliği. Karadeniz Teknik Üniversitesi Orman Fakültesi, Genel ve Fakülte Yayınları. 239(41):344.

Eker, M. 2022. Time Measurement and Recording Tools for Work Study in Manual Forest Operations. Soil, Forest and Water Research Giving Life to Humans. Klaipeda, SRA Academic Publishing. 119-146.

Erdaş, O., Acar, H. H., Eker, M. 2014. Orman Ürünleri Transport Teknikleri. Karadeniz Teknik Üniversitesi Orman Fakültesi, Genel ve Fakülte Yayınları. 233(39):504.

GDF (General Directorate of Forestry), 1996. Communiqué No. 288 on the Production of Primary Forest Products. General Directorate of Forestry, Ankara, Türkiye.

GDF (General Directorate of Forestry), 2020. Official Communique about Harvesting of Wood-based Forest Products – No:310. General Directorate of Forestry, Ankara, Turkey. https://www.ogm.gov.tr/ekutuphane/Tebligler (Accessed: 13 February 2020).

GDF (General Directorate of Forestry), 2024. Forestry Statistics 2023. Offical Statistics. https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler (Accessed 10.09.2024)

Magagnotti, N, Spinelli, R. 2012. Good Practice Guidelines for Biomass Production Studies. Sesto Fiorentino: CNR Ivalsa, Italy, 50.

Malinovski, R. A., Malinovski, J. R., Nutto, L., Bianchi, É. C. 2016. Harvesting Costing. In: Pancel, L., Köhl, M. (eds) Tropical Forestry Handbook. Springer, Berlin, Heidelberg.

Şafak, İ., Eker, M., Erdem, M., Turan, İ. 2019. Time and Motion Analysis On Cable Skidding With Agricultural Tractors Of Coniferous Logs. Turkish Journal of Forestry Research. 6(1): 58-47.

Yıldırım, M. 1989. Ormancılık İş Bilgisi. İstanbul Üniversitesi, Orman Fakültesi Yayınları, İstanbul.

# Identification of Potential Hydraulic Structures on Forest Roads Using ArcGIS® ModelBuilder

**Taha Yasin Hatay***, **Selçuk Gümüş**

Karadeniz Technical University, Faculty of Forest, Department of Forest Engineering, Trabzon, Türkiye
*tyhatay@ktu.edu.tr

**Abstract**
Forest roads cause various impacts on the ecosystem during planning and construction activities. Determining the locations of potential hydraulic structures (bridges, culverts, etc.) in the areas crossed by forest roads is of great importance for both infrastructure planning and environmental protection. This study aims to effectively and quickly identify the points where forest roads intersect with stream beds. A model was created using the ModelBuilder tool of ArcGIS Desktop. The model first identifies watershed boundaries and stream beds through watershed analysis. Then, it marks the coincidence points of these stream beds and forest roads as potential art structure locations. The model identified 4 micro watersheds in Maçka Forest Sub-District Directorate. 20 existing and 10 planned forest roads crossed the stream bed 317 times. In the study area, it was determined that an average of 2 hydraulic structures can be planned for a 1 km forest road. This model can be used in modeling processes related to forest roads and watersheds. It can provide important data to forest road planners and environmental planners for infrastructure projects planned in the area. The accuracy and usefulness of the developed model is open to be supported and improved by field studies and literature reviews.

***Keywords:*** *Forest roads, hydraulic structures, GIS, ArcGIS, ModelBuilder*

## 1. Introduction

Forest roads are an important support for the sustainable management and operation of forests. Forest roads serve many purposes such as wood production, firefighting, tourism, supervision of forestry activities and biodiversity protection (Hayati et al., 2012; Çalışkan, 2013). Planning of forest roads is done to ensure that these activities are carried out efficiently and sustainably. The planning process considers factors such as topography, slope, size of the forest area, environmental impacts of the road and economic factors. Forest roads have strategic importance in fulfilling the demand for forest products. Furthermore, forest roads not only provide financial benefits but have also been associated with negative environmental impacts such as habitat fragmentation, biodiversity loss, and ecosystem degradation in forested areas (Gucinski et al., 2001).

Excessive and unplanned construction of forest roads can have negative impacts on natural ecosystems. Incorrect route choices can lead to environmental problems such as soil erosion, pollution of water resources and habitat fragmentation. Therefore, environmental sustainability principles are considered in the construction of forest roads. Planning processes should be carried out carefully to ensure that road networks minimise damage to natural ecosystems. In addition, during the construction of forest roads, negative impacts on hydrological processes in the region may occur. These impacts can lead to increased soil erosion, sediment accumulation, and pollution of water resources, and consequently to a decrease in water quality (Grace and Clinton, 2007; Grigolato, 2019; Kastridis, 2020).

Figure 1. Illustration of the harmful environmental effects that may occur between forest roads and streams (this image was created with AI)

The disadvantages of forest roads that cause water quality problems include damage to the natural environment from the materials used for construction and maintenance, increased erosion, and pollution of water resources (Acar, 2005; Akbarimehr and Naghdi, 2012). Among other negative impacts, the materials used for the construction and maintenance of forest roads can lead to increased negative impacts such as erosion and landslides (Zare et al., 2021). This suggests that tarmac-paved roads are less effective on erosion, especially in wet weather, but local roads are more effective on erosion (Akbarimehr and Naghdi, 2012) (Figure 1). As another example, other factors that adversely affect the water quality of forest roads include chemicals (e.g., pesticides, insecticides, and de-icers) released during road construction and maintenance that enter the water and contaminate water resources (Coffin, 2007). The planning and construction of forest roads can have negative impacts on water quality for all these reasons. These impacts can be summarised as misuse of construction materials, erosion, chemical pollution, and pollution of water resources. To minimise these impacts, careful planning and environmental sensitivity are required during forest road construction and maintenance.

Forest road construction activities in Türkiye have made significant progress since the planning process started in 1964. Within the scope of the first 10-year planning process, 20,691 km of roads were constructed in 1974, and 144,425 km of roads were planned. Subsequently, 79,047 km of forest roads were constructed in 1984, 116,646 km in 1991, 133,393 km in 2004, and finally 212,979 km by 2022 (Figure 2). Although this process has increased the productivity of forestry activities in Türkiye, forest road construction can create environmental impacts such as soil erosion, degradation of water resources and ecosystem fragmentation. As can be seen, the fast, practical and accurate implementation of forestry construction works, which have direct impacts on water resources, is the most important planning stage.


Figure 2. Construction and planning stages of forest roads in Türkiye by year

The use of GIS in the planning stage of forest roads makes an important contribution to reducing environmental impacts. Since GIS is a powerful tool for collecting, analysing and visualising environmental data, it is an important tool for the accurate planning of forest roads and for minimising the environmental damage of construction. In areas with construction activities, natural drainage systems may be degraded. This can lead to water overflows, flood risk or soil erosion. GIS allows for a detailed analysis of drainage networks and water flow paths. In road construction, drainage structures (culverts, water channels, ditches) need to be accurately planned to safely remove water from the road. GIS can be an important tool for placing drainage structures at the most suitable locations (URL-2, 2024). Identifying the points where drainage structures are needed is possible by analysing the water flow paths correctly. With the help of GIS, the locations of culverts and channels required for the smooth flow of water from the roads can be determined. Drainage lines can be directed naturally without damaging water resources.

This study aims to create an ArcGIS model that can quickly identify watershed boundaries during the planning of forest roads and determine the water lines where forest roads intersect. This model will be developed into a module that can reach the end user with the help of Python coding. Thus, at the planning stage, planners will be able to determine the amount of potential hydraulic structures that can be used on forest roads and their application locations more quickly and easily.

## 2. Material and Methods

The boundaries of Maçka Forest Sub-District Directorate were selected as the study area. There is 18,180.60 ha of forest area within the borders of Maçka Forest Sub-District Directorate (Figure 3). There are 137,85 km of forest roads within the study area. Considering that they will be used for all kinds of forestry activities, the length of the roads is approximately 300 km. The reason for the selection of this study area is that there is a lot of micro-basin structure and the intersection of forest roads with stream structures. When a 100-meter buffer was placed on the forest roads in the study area, it was determined that 17 landslide areas in the region were within the buffer boundaries of the forest roads. 12 of these areas were found to be in areas where they meet with water lines. For these reasons, it is necessary to determine the potential hydraulic structures in the study area as soon as possible.

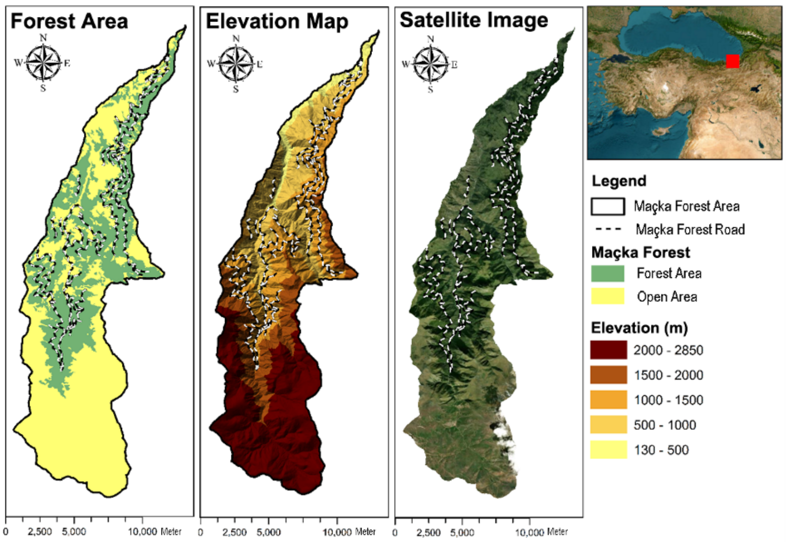



Figure 3. Forest area, elevation map and satellite image of the study area

In the study, a model was created with ArcGIS Model Builder (Figure 4). The model consists of 3 parameters. These parameters are (1) the boundary layer, (2) the contour layer, and (3) the forest roads layer.

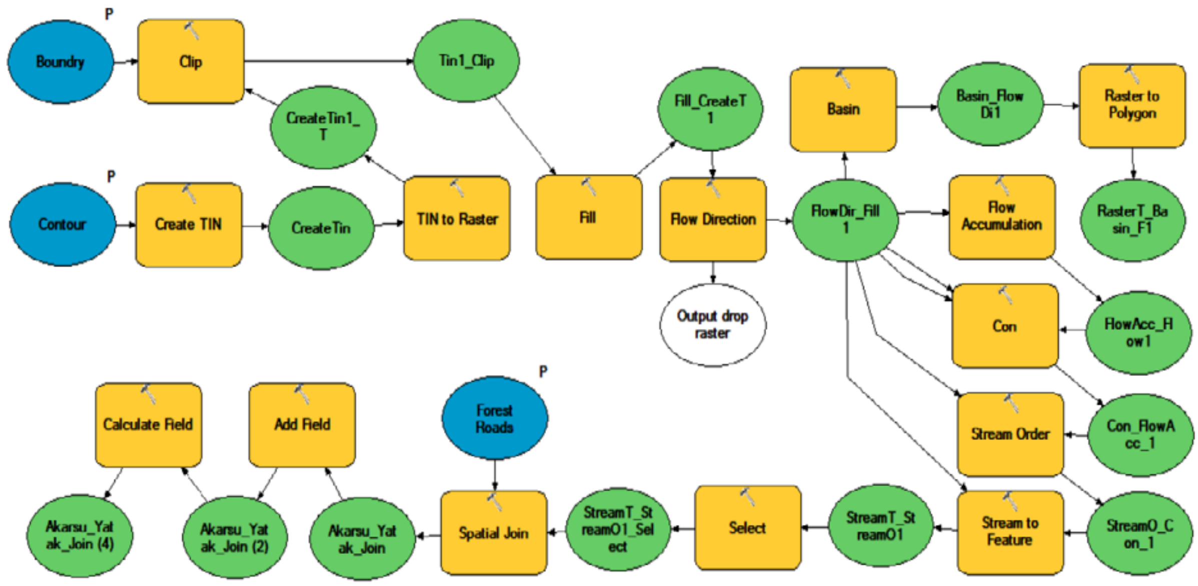



Figure 4. Structure of the ArcGIS model designed for the study

When the model structure is examined, the working process starts with creating a TIN (triangular irregular networks) structure from the contour structure covering the work area. This TIN structure is then clipped with the boundaries of the study area. Thus, the elevation structure of the study area is revealed. The TIN structure is converted to raster format. After converting to raster format, the basin structure of the area is started to be created. In the basin structure, flow directions are determined with the 'Flow direction' process. Then, with the help of flow directions, basin boundaries are determined. Here, the downstream and upstream lines of the water are determined while the basin boundaries are revealed. The obtained basin boundaries are converted into polygons (Basin >> Raster to Polygon). Then, 'Flow Accumulation', 'Con', 'Stream Order', 'Stream to Feature' and 'Select' operations are performed. To briefly explain these operations;

'Flow Accumulation' calculates the accumulated weight of all cells arriving at each downslope cell in the output raster. This produces an average weighted flow direction that depends on the slope direction between the raster pixels.

'Con' creates a true/false loop using programmatic logic on the raster. It is used to determine the direction of the flow in the decision phase, whether to move to the next pixel or not.

'Stream Order' allows the sorting stage to be performed after the direction of the flow. This process ensures that the water lines are ordered within themselves.

'Stream to Feature' converts the water line created in the previous stages into a feature layer. In other words, the feature values obtained reveal the entire water line layer.

'Select' selects all feature values to reveal the exact structure of the water lines. Due to the regional nature of the outputs, 'grid_code >= 5' is set in the select stage. The grid_code structure may vary regionally. However, for convenience, grid_code structures greater than 5 fully reveal dry streams, perennial streams, and rivers.

Finally, the 'Spatial Join' operation was used in the model structure in order to identify the areas where the created stream structures intersect with forest roads. Thus, the number of potential hydraulic structures in the attribute table of forest roads will be added directly. After the model design and processing, it was converted into a module program with the Arcpy library using the Python programming language (URL-1, 2024). This program aims to enable the end user to perform the processing process with their own data (Figure 5).

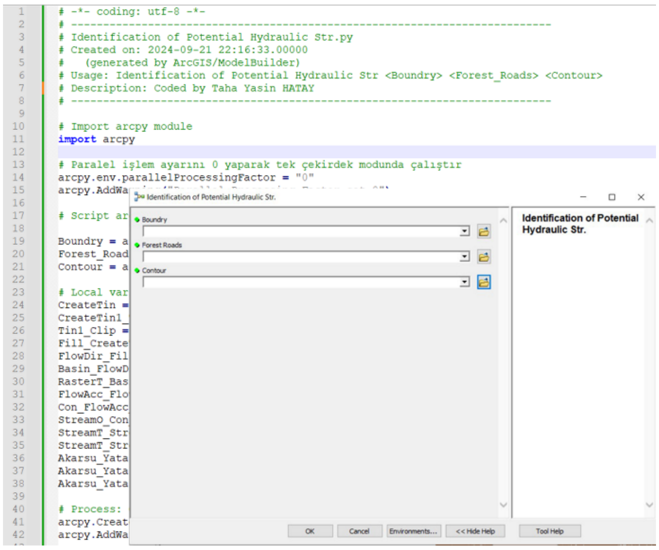


Figure 5. Code structure with Arcpy and ArcGIS view of the application

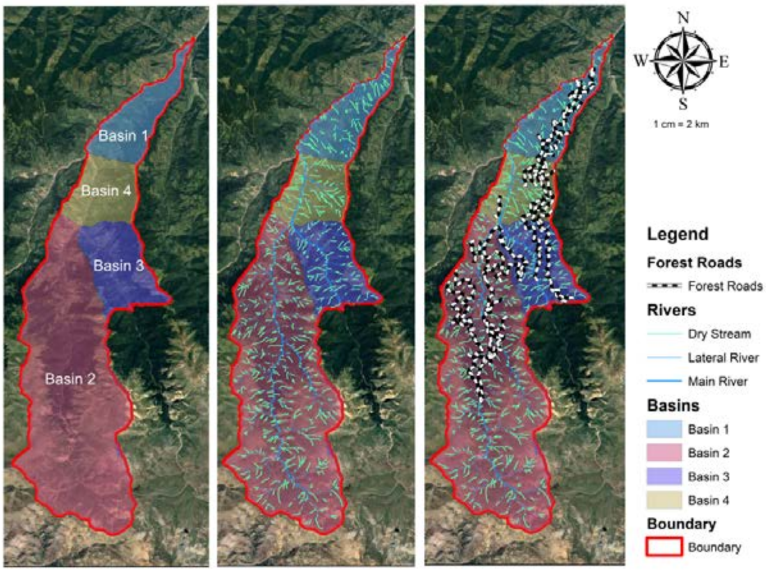


Figure 6. Combining the basin structure and stream structure obtained from the study area with forest roads

## 3. Result and Discussion

With the ArcGIS module created the boundaries of the micro basins within the borders of Maçka Forest Sub-District Directorate were determined. Depending on these micro basin boundaries, stream structures and intersection points with forest roads were determined (Figure 6). With the basin data obtained, the characteristics of the basins and streams were revealed (Table 1).

Table-1. General characteristics of basin and stream structures

| Basin Structures | | | |
|---|---|---|---|
| Basins | Area ($km^2$) | Length (km) | Form Factor |
| Basin-1 | 21 | 10.010 | 0.210 |
| Basin-2 | 115 | 22.490 | 0.227 |
| Basin-3 | 25 | 6.790 | 0.542 |
| Basin-4 | 20 | 5.690 | 0.618 |
| Total | 181 | 50,955 | |

| Stream Structures | | |
|---|---|---|
| Structures | Length (m) | Connection (N) |
| Dry Stream | 267,156 | 25,152 |
| Lateral River | 182,274 | 19,847 |
| Main River | 52,872 | 5,956 |
| Total | 502,303 | 50,955 |

According to Table 1, the largest area is in Basin-2. This basin has an area of 115 km² and a length of 22.49 km. On the other hand, the smallest area belongs to Basin-4, which has an area of 20 km² and a length of 5.69 km. When the form factor is analysed, the basin with the highest value is Basin-4 (0.618), which indicates that the basin has a more rounded shape and water can flow faster. The lowest form factor was observed in Basin-1 with 0.210. The lowest form factor was observed in Basin-1 with 0.210. The form factor was calculated by the formula $R_f=A/L_b^2$ in accordance with the study of Horton (1945). Form factor makes sense in the shape of the basin and the collection time of the water. Basins with low form factor values are narrow and long, which means that the accumulation time of water is longer and lower flows occur (Horton, 1932). On the contrary, basins with high form factor values have more rounded or almost circular shapes, which means that water accumulation time is shorter, and flows are higher (Horton, 1932; Kutukcu et al., 2015).

When the form factor of the basins in the study area is less than 1, it indicates that the length of the basin is greater than its width. A form factor greater than 1 indicates that the basin has a long structure. Since the accumulation time of water is longer in basins with low form factor, the risk of flash flood is lower (Bishop and Victoria, 2001; Kutukcu et al., 2015; Veeranna et al., 2017; Erol Görür and Karadeniz, 2018). Considering these distributions, it is concluded that different planning and construction activities should be carried out depending on the hydrological characteristics of each basin. According to Table 1, when the stream structure is analysed, it is seen that the total length of dry streams is 267,156 km. The area has the highest number of dry streams in terms of structure. The length of the lateral streams is 182,274 km. The length of the mainstream fed by these two stream structures is 52,872 km. The expected values have emerged in terms of length. Likewise, when the connection points of the streams are examined, it is determined that the connection point of the mainstream is the lowest and the connection point of the dry stream is the highest. These connection points are called nodes and are created by ArcGIS depending on the slope.

The locations where potential art structures can be applied on the forest roads route were identified (Table 2). According to Table 2, the total length of forest roads is 137.85 km. The longest road is 4380-015 with a length of 16.336 km, which has 71 potential hydraulic structures and shows the highest structure density with 4.3 structures per kilometre. In contrast, there are no hydraulic structures on the forest road 4380-009. It is seen that long roads show a higher need for potential hydraulic structures, while short forest roads can show high structure density only if local hydrographic conditions exist. On average, 2 hydraulic structures are constructed per kilometre on forest roads. When this average figure is analysed, a remarkable finding emerges. This finding is that although some forest roads are short, their potential hydraulic structure density is higher. These forest roads are 4380-027 (3.5), 4380-018 (3.7) and 4380-002 (3.3). In these forest roads, it has been determined that slope and aspect differences are more, and construction activities should be more.

Table 2. Number of potential hydraulic structures detected on forest roads and number of potential hydraulic structures per kilometer

| Road Code | Road Name | Length (km) | Potenial Hyd. Str. (N) | Structures (per km) |
|---|---|---|---|---|
| 4380-001 | Teraziler – Kapuköy | 13.189 | 40 | 3,0 |
| 4380-002 | Mucura Mah. – Ormandibi | 2.735 | 9 | 3,3 |
| 4380-003 | Kirazlı - 17 nolu Bölme | 2.012 | 2 | 1,0 |
| 4380-004 | Zaferli – Süleymanağa | 3.375 | 4 | 1,2 |
| 4380-005 | Zaferli D. - Cuma D. | 7.719 | 19 | 2,5 |
| 4380-006 | 47 nolu Bölme - Kazankıran Mezrası | 1.946 | 3 | 1,5 |
| 4380-007 | Bahçeli Mah. - Bakırcılar Deresi | 2.281 | 5 | 2,2 |
| 4380-008 | Yukarı Mah. - Kıran Mah. | 2.911 | 5 | 1,7 |
| 4380-009 | Balkız Mezra – Pilavdağı | 2.213 | 0 | 0,0 |
| 4380-010 | Balkız Mezra - Yazlık M ezra | 3.907 | 6 | 1,5 |
| 4380-011 | Kınalıköprü - 65 nolu Bölme | 1.977 | 4 | 2,0 |
| 4380-012 | Cuma Dere – İmamınköprüsü | 9.294 | 21 | 2,3 |
| 4380-013 | Cuma Dere - 177 nolu Bölme | 10.563 | 21 | 2,0 |
| 4380-014 | Pangal Dere - Cuma Mezra | 2.450 | 4 | 1,6 |
| 4380-015 | Kınalıköprü -255 nolu Bölme | 16.336 | 71 | 4,3 |
| 4380-016 | Orta Mah. - Medoş Mah. | 5.597 | 7 | 1,3 |
| 4380-017 | 104 nolu Bölme – Dikilitaş | 1.934 | 3 | 1,6 |
| 4380-018 | 104 nolu Bölme - 126 nolu Bölme | 1.357 | 5 | 3,7 |
| 4380-019 | Larhan – Kırantaş | 3.798 | 7 | 1,8 |
| 4380-020 | Uzun Mezra - 155 nolu Bölme | 4.457 | 7 | 1,6 |
| 4380-021 | Meşeiçi Hanları - 203 nolu Bölme | 8.664 | 12 | 1,4 |
| 4380-022 | 142 nolu Bölme - Akarsu mezra | 6.563 | 14 | 2,1 |
| 4380-023 | 159 nolu Bölme -177 nolu Bölme | 1.736 | 3 | 1,7 |
| 4380-024 | Kireçocağı - 164 nolu Bölme | 2.101 | 4 | 1,9 |
| 4380-025 | Acısu - 236 nolu Bölme | 3.225 | 6 | 1,9 |
| 4380-025-1 | 225 nolu Bölme - 191 nolu Bölme | 3.192 | 3 | 0,9 |
| 4380-026 | 203 nolu Bölme - 233 nolu Bölme | 4.021 | 9 | 2,2 |
| 4380-027 | Acısu - 236 nolu Bölme | 2.312 | 8 | 3,5 |
| 4380-027-1 | Acısu - 236 nolu Bölme | 1.075 | 2 | 1,9 |
| 4380-028 | Dipyatak D. - Taryayla D. | 4.604 | 11 | 2,4 |
| | TOPLAM | 137.85 | 315 | |

Caliskan and Acar (2003) tried to determine the hydraulic structures of forest roads in their study. However, the study was conducted only on a 35 km forest road. The area of the study is the neighbouring basin of our study area. Here, it was determined that there were 2.3 hydraulic structures per kilometre. This value is compatible with our study. Ünver (2013), in his study, determined the average of hydraulic art structures on forest roads as 1.03 pieces per kilometre. However, he states that the art structures in the study area are inadequate, and the existing hydraulic structures do not fully fulfil their duties due to incorrect application.

## 4. Conclusion and Suggestions

In this study, it is aimed to determine the basin area of the desired area, to reveal the upstream and downstream flow directions within the basin area and to reveal the intersection points of the water lines and forest roads. These intersection points are potential points where hydraulic structures are applied. For these processes, ArcGIS model and program were written using Arcpy library with Python programming.

In the study, it was determined that 2 art structures could potentially be applied per kilometre. Although some of the forest roads are short, it is seen that the potential art structure density is higher. This indicates that there are more slope and aspect differences in the route of the forest road, and at the same time, construction activities should be more in these areas. The study clearly reveals the basin boundaries. In addition, the form factors of the basin areas were revealed. With this form factor, the water accumulation capacity of the basins can be evaluated. In accordance with the literature, the connection points called nodes of the water line structures within the basin were revealed. These connection points are gradually increasing as mainstream, lateral stream and dry stream respectively.

This study is a methodological study. In the content of the study, the creation of the model and the writing of the program is an original value. The findings of such studies are actually much more than the detected findings. The model and ArcGIS module, which constitute the main structure of the study, have been shared with the end user via github (URL-1, 2024). In the future, the program can be integrated with web mapping systems via online GIS. Thus, it is foreseen that the end user, which we call the planner, will save time and cost during the planning phase.

**Acknowledgement**

This study was prepared with the contributions of the TÜBİTAK (The Scientific and Technological Research Council of Türkiye) project coded 122O785.

**References**

Acar, H. H. 2005. Orman Yolları. Trabzon: Karadeniz Teknik Üniversitesi Ders Teksirleri Serisi:82.

Akbarimehr, M., Naghdi, R. 2012. Reducing erosion from forest roads and skid trails by management practices. Journal of Forest Science, 58, 165–169. doi:10.17221/136/2010-jfs

Bishop, V., Prosser, R. 2001. Water resources: process and management. London: Collins Educational.

Coffin, A. W. 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography, 15, 396–406. doi:10.1016/j.jtrangeo.2006.11.006

Çalışkan, E., Acar, H. H. 2011. Orman Yollarinda Hidrolik Sanat Yapilarinin Incelenmesi. Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi, 4(1), 137-143.

Çalışkan, E. 2013. Environmental impacts of forest road construction on mountainous terrain. Iranian Journal of Environmental Health Science & Engineering, 10, 1–8. doi:10.1186/1735-2746-10-23

Erol Görür, A., Karadeniz, C. 2018. Morfometrik parametrelerin havza hidrolojisi bakımından değerlendirilmesi. Turkish Journal of Forestry, 19(4), 447-454. https://doi.org/10.18182/tjf.476776

Grace, J., Clinton, B. 2007. Protecting soil and water in forest road management. Transactions of the Asabe, 50, 1579–1584. doi:10.13031/2013.23969

Grigolato, S. 2019. Considerations on forest road networks and related works to support the implementation of the operative guidelines of the consolidate law on forests and forest chains. Considerations on forest road networks and related works to support the implementation of the operative guidelines of the consolidate law on forests and forest chains. doi:10.3832/efor3175-016

Gucinski, H., Furniss, M. J., Ziemer, R. R., Brookes, M. H. 2001. Forest roads: a synthesis of scientific information (Vol. 509). Forest Service: US Department of Agriculture. doi:10.2737/pnw-gtr-509

Hayati, E., Majnounian, B., Abdi, E. 2012. Qualitative evaluation and optimization of forest road network to minimize total costs and environmental impacts. Iforest - Biogeosciences and Forestry, 5, 121–125. doi:10.3832/ifor0610-009.

Horton, R. E. 1932. Drainage-basin characteristics. Transactions, American geophysical union, 13(1), 350-361.

Horton, R. E. 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological society of America bulletin, 56(3), 275-370.

Kastridis, A. 2020. Impact of forest roads on hydrological processes. Forests, 11, 1201. doi:10.3390/f11111201

Kutukcu, A., Kaya, S., Kabdasli, S., & Gazioglu, C. 2015. Nehir havzalarının morfolojik karakteristiklerinin CBS destekli nümerik modeller kullanılarak analizi. TUFUAB VIII. Teknik Sempozyumu, 21-23.

URL-1. (2024, September 9). Code Document Website of the Study: https://github.com/ArresT-AnarchY/Identification-of-Potential-Hydraulic-Structures

URL-2. (2024, September 9). >Basin (Spatial Analyst) ArcMap | Documentation: https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/basin.htm

Ünver, S. 2013. Orman Yollarında Puanlandırma Yöntemiyle Yol Kalite Sınıflarının Belirlenmesi: Karanlıkdere Örneği. Kastamonu University Journal of Forestry Faculty, 13(2), 211-219.

Veeranna, J., Gouthami, K., Yadav, P. B., Mallikarjuna, V. R. 2017. Calculating linear and areal and relief aspect parameters using Geo-Spatial Techniques (ArcGIS 10.2 and SWAT model) for Akkeru River Basin Warangal. International Journal of Current Microbiology and Applied Sciences, 6(10), 1803-1809.

Zare, N., Hosseini, S. A., Hafizi, M. K., Najafi, A., Majnounian, B., Geertsema, M. 2021. A Comparison of an adaptive neuro-fuzzy and frequency ratio model to landslide-susceptibility mapping along forest road networks. Forests, 12, 1087. doi:10.3390/f12081087.

# Assessment of Machine-Based Hazards and Risks in Forestry Transport Works Using HRNS and TOPSIS Methods

**Hafiz Hulusi Acar, Tolga Barişik***

Istanbul Yeni Yuzyil University, Faculty of Health Sciences, Department of Occupational Health and Safety, Istanbul, Türkiye
* tolga.barisik@yeniyuzyil.edu.tr

## Abstract

While transportation work in forestry is crucial, it also poses major hazards and threats to people and the working environment. Specifically, the hazards and risks provided by the machines used have severely detrimental consequences. The HRNS (Hazard Rating Number System) technique was utilized in this study to assess the hazards and risks posed by forestry transport machines. The dangers of machines employed in transportation and construction, such as mechanical, electrical, and working without machine protection, were assessed, and the risks associated with these hazards were identified. The five biggest risk criteria identified by HRNS were listed using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) technique, and five alternative measures for each were offered. The most relevant one of these measures was selected. The study's goal is to reduce machine-related workplace accidents and improve risk management in the forest sector. As a result, reducing machine-related occupational accidents is crucial for both worker safety and productivity. Machine-related mishaps can result in significant injuries and financial losses. Hazards were discovered using the HRNS approach, and the risks associated with these hazards were assessed. The highest risk criteria were then identified using the TOPSIS technique, and alternative measures were given. As a consequence of the research, feasible and effective strategies were identified to reduce machine-related risks in forestry transport operations, and the most appropriate measure was chosen. This paper is a significant resource for the sector.

***Keywords:*** *Forestry transport, machinery safety, HRNS Method, TOPSIS method, risk assessment, occupational health and safety*

## 1. Introduction

The forestry sector is an area that poses high risks in terms of occupational health and safety, especially due to the variety and density of machines used in transport operations. The machines used in this sector increase the dangers to which employees are exposed and pave the way for occupational accidents. Machine-related occupational accidents can usually lead to serious injuries, long-term loss of labor, and significant material damage (Acar, 2017). Therefore, preventing occupational accidents and improving risk management in the forestry sector are of great importance.

In this study, the hazards and risks that may be caused by machines used in transport operations in forestry were analyzed in detail with the Hazard Numbering System (HRNS) method. Within the scope of the study, risk factors such as mechanical, electrical, and working without machine guards were evaluated and the hazards arising from these factors were determined. The highest risk ones among the identified hazards were ranked with the

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method and alternative measures were presented to minimize these hazards. Three expert opinions were obtained for this method. Calculations were made according to the scores given by the experts to the criteria.

The machines used in forestry transport are generally designed for the tough working conditions that include processes such as cutting, transporting and loading trees. Some basic machines used in forestry transport:

- ✓ Skidder: Heavy machinery that removes tree trunks from a forest area and transports them to a collection area. Skidders are usually equipped with cable or grapple grippers and can move over difficult terrain.
- ✓ Forwarder: Machines used to transport felled tree trunks. It can load tree trunks using a hydraulic arm and transport them on a wheeled platform.
- ✓ Harvester: Multifunctional machinery that performs tree felling, branch clearing and trunk cutting operations. Harvesters are especially suitable for selective cutting operations.
- ✓ Log Loader: Machines used to load logs onto trucks. These machines have powerful hydraulic arms to lift and arrange heavy logs.
- ✓ Bulldozer: Heavy machinery used to clear forest paths, level the terrain or remove obstacles such as rocks and soil. Bulldozers can level the ground and clear the road with their large blades.
- ✓ Chainsaw: Portable chainsaw used in tree felling and branch clearing operations. This tool, usually used manually, functions as an auxiliary equipment for larger machines.
- ✓ Excavator: Machines used to dig soil and rocks, level hilly terrain and open water drainage channels. It is also used in forestry in some cases.
- ✓ Feller Buncher: Machines that cut trees and place multiple trees together at the same time. These machines are usually used for mass cutting operations in forest areas.
- ✓ Log Truck: Trucks specially designed to transport cut tree trunks from the forest to processing facilities. These trucks are equipped with special racks to transport the logs safely.

These machines are used to increase efficiency and speed up work processes in forestry transport operations (Akgül et. al., 2021). At the same time, the use of appropriate equipment in terms of occupational safety is critical to ensure the safety of employees. The aim of this research is to prevent occupational accidents by effectively managing machine-related hazards and risks in forestry transport operations. The study aims to increase the safety and work efficiency of sector employees by offering an innovative approach to increase occupational health and safety in this field. This requirement is of critical importance in terms of minimizing labor and material losses caused by occupational accidents (Özkılıç, 2005). In this context, the study offers practical and effective solutions that will contribute to the improvement of safety standards in the sector.

The five most risky criteria determined as a result of the HRNS method used in the study are as follows:

- ✓ Machine Failures and Lack of Maintenance: Machines that are not regularly maintained or are faulty can create dangerous situations that can lead to work accidents.
- ✓ Inadequate Training and Awareness: If machine operators and employees do not receive sufficient training, accidents resulting from improper use can occur.

- ✓ Electrical Hazards: Electrical failures or insulation faults can cause serious hazards such as electric shock and fire.
- ✓ Inadequacy or Lack of Machine Guards: Exposed machine parts or lack of protective equipment can cause serious injuries.
- ✓ Difficult Working Conditions: Difficult terrain in forested areas, slippery surfaces and weather conditions can make machine use more dangerous.

The five alternatives determined for the measures to be taken against the 5 criteria that emerged are as follows:

- ✓ Regular Maintenance and Inspection: Regular maintenance and inspection of machinery and equipment helps prevent malfunctions and accidents.
- ✓ Training Programs and Awareness: By organizing regular training programs for operators and other employees, safety awareness in machine use can be increased.
- ✓ Electrical Safety Measures: Electrical hazards can be prevented by regularly checking electrical systems, ensuring insulation and using appropriate equipment.
- ✓ Use of Machine Protective Equipment: Complete and correct installation of machine guards, as well as training employees to use these equipment, can reduce accidents.
- ✓ Establishment of Safe Working Procedures: In order to minimize risks in difficult working conditions, appropriate working procedures can be established and employees can be ensured to act in accordance with these procedures.

These measures can contribute to the effective management of machinery-related risks in forestry transport operations and the prevention of occupational accidents.

## 2. Method

In this study, the HRNS method was used. This method was used to examine the risks of some machines used in transport operations. Then, the precautions to be taken were determined with the TOPSIS method. Three expert opinions were taken for the TOPSIS method.

### 2.1. Hazard Rating Number System (HRNS)

More realistic values are obtained in this method, which also includes the man-hour factor (Table 1). In the HRNS method, the risk score (HRNS) is determined by multiplying the probability of the event occurring (P), the frequency of being in the hazard zone (F), the severity of injury (S) and the number of people at risk (NP) (Bilir et. al., 2017).

The equation used to determine sub-scores for risks according to the Hazard Rating Number System (HRNS) method; (Bilir et. al., 2017).

$$HRNS=P\times F\times S\times NP \quad (1)$$

According to the HRNS method, if the same hazards and risks exist in two work areas and different numbers of employees work (for example, one of the two units is 8 and the other is 80 people), it would not be appropriate for the identified risks to give the same score and for the priorities of the measures to be equal (Table 2). Therefore, it is argued that the number of people plays an important role in determining the risk score. Risk scores will be determined using the HRNS parameters multiplication scale (Akkoyun et. al., 2021).

Table 1. HRNS Multiplication Scale of Parameters

| Probability (P) | | Frequency (F) | | Number of People (NP) | | Severity (S) | |
|---|---|---|---|---|---|---|---|
| Values | Explain | Values | Explain | Values | Explain | Values | Explain |
| 0.033 | Almostly impossible | 0.5 | Once a year | 1 | 1-2 | 0.1 | Scratch |
| 1 | Very difficult | 1 | Once a month | 2 | 3-7 | 0.5 | Cut |
| 1.5 | Difficult | 1.5 | Once a week | 4 | 8-15 | 1 | Small bone fracture |
| 2 | Possible | 2 | Daily | 8 | 16-50 | 2 | Major bone fracture |
| 5 | Possible | 4 | Hourly | 12 | +50 | 4 | Loss of 1-2 fingers |
| 8 | Likely | 5 | Continuously | | | 8 | Loss of limbs |
| 10 | Most likely | | | | | 10 | Serious persistent illness |
| 15 | Definitely | | | | | 15 | Death |

Table 2. Determination of HRNS Risk Score

| COLOR | HRN/Risk | Risk |
|---|---|---|
| 1 | 0-1 | Negligible Risk |
| 2 | 2-5 | Very Low Risk |
| 3 | 6-15 | Low Risk |
| 4 | 16-50 | Considerable Risk |
| 5 | 51-100 | High Risk |
| 6 | 101-500 | Very High Risk |
| 7 | 501- | Extremely High Risk |

**2.2. TOPSIS Method**

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), one of the Multi-Criteria Decision Making (MCDM) methods, takes into account both the distance of each alternative from the positive ideal and the distance of each alternative from the negative ideal point. In other words, the best alternative should have the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal (Ching-Shih, 2008). The method steps are 5 (Madi et. al., 2015; Silvestre et. al., 2012). They are as follows:

STEP 1: Normalization of the decision matrix

Equality (2) is used for normalization.

$$r_{ij}(\mathrm{x}) = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad i = 1, \ldots, m \ ; j = 1, \ldots \ , n \tag{2}$$

STEP 2: Calculating the weighted normalized decision matrix

In Equation (3) below, the normalized matrix is multiplied by the weight of the criteria.

$$v_{ij}(\mathrm{x}) = w_j r_{ij}(x) \quad i = 1, \ldots, m \ ; j = 1, \ldots \ , n \tag{3}$$

STEP 3: Determining positive ideal and negative ideal solutions
The purpose of the TOPSIS method is to calculate the degree of distance of each alternative from the positive and negative ideals. Therefore, in this step, the positive and negative ideal solutions are determined according to the following equations.

$$A^{+} = (v_1^{+}, v_2^{+}, \dots, v_n^{+}) \quad (4)$$

$$A^{-} = (v_1^{-}, v_2^{-}, \dots, v_n^{-+}) \quad (5)$$

Like this;

$$v_j^{+} = \{(max\ v_{ij}(x) | j\epsilon j_1), (min\ v_{ij}(x) | j\epsilon j_2)\}\ i = 1, \dots, m \quad (6)$$

$$v_j^{-} = \{(min\ v_{ij}(x) | j\epsilon j_1), (max\ v_{ij}(x) | j\epsilon j_2)\}\ i = 1, \dots, m \quad (7)$$

Here $j_1$ and $j_2$ represent negative and positive criteria, respectively.

STEP 4: Distance from ideal solutions, positive and negative
The TOPSIS method ranks each alternative according to its relative closeness to the positive ideal and its distance from the negative ideal. Therefore, in this step, the distances between each alternative and the positive and negative ideal solutions are calculated using the following equations.

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} [v_{ij}(x) - v_j^{+}(x)]^2}\ ,\ i = 1, \dots, m \quad (8)$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} [v_{ij}(x) - v_j^{-}(x)]^2}\ ,\ i = 1, \dots, m \quad (9)$$

STEP 5: Calculating the relative closeness of the alternatives to the ideal solution
In this step, the relative proximity degree of each alternative to the ideal solution is obtained by the following Equation (10). If the relative proximity degree has a value close to 1, this means that the alternative is shorter than the positive ideal solution and longer than the negative ideal solution.

$$C_i = \frac{d_i^{-}}{(d_i^{+} + d_i^{-})}\ ,\ i = 1, \dots, m \quad (10)$$

**3. Results**
This study was applied to the machines used in forestry transportation operations. The hazards that may occur in the machines are mechanical, electrical, etc. workplace hazard factors. Thus, the hazards of these factors are determined and the risks are eliminated (Cheng-Min et. al,, 2001). The precautions to be taken are determined according to the risk priority level (Soba et. al., 2011). The HRNS method was used to evaluate the risks that occur during the operation of the machines in the workplace. In Table 3, the HRNS method application is given.

As seen in the table above, the results of the risks are the same. After this point, the degrees of the most appropriate precaution alternatives for the risk factors in the table were determined using the TOPSIS Method. The risks in this table were determined as criteria. In addition, the precautions to be taken were determined as alternatives. The operations and results for this section are shown in the tables below.

Table 3. HRNS Study

| NO | ACTIVITY | HAZARD | RISK | AFFECTED PERSON(S) | RISK ASSESSMENT RESULT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | P | F | S | NP | R | HRN/Risk | RISK RESULT |
| 1 | Transport Works | Workplace and Machine Use | Injury or Death Due to Machine Failures and Lack of Maintenance | All Employees | 8 | 2 | 15 | 4 | 960 | 7 | Death or Serious Injury |
| 2 | Transport Works | Workplace and Machine Use | Injury or Death as a Result of Inadequate Training and Awareness | All Employees | 8 | 2 | 15 | 4 | 960 | 7 | Death or Serious Injury |
| 3 | Transport Works | Workplace and Machine Use | Injury or Death from Electrical Hazards | All Employees | 8 | 2 | 15 | 4 | 960 | 7 | Death or Serious Injury |
| 4 | Transport Works | Workplace and Machine Use | Injury or Death Due to Inadequacy or Lack of Machine Guards | All Employees | 8 | 2 | 15 | 4 | 960 | 7 | Death or Serious Injury |
| 5 | Transport Works | Workplace and Machine Use | Injury or Death Due to Harsh Working Conditions | All Employees | 8 | 2 | 15 | 4 | 960 | 7 | Death or Serious Injury |

Table 4. Characteristics of Criteria

| | Criteria | Weight |
|---|---|---|
| 1 | Machine Failures and Lack of Maintenance | 0.25 |
| 2 | Inadequate Training and Awareness | 0.3 |
| 3 | Electrical Hazards | 0.2 |
| 4 | Inadequacy or Lack of Machine Guards | 0.25 |
| 5 | Difficult Working Conditions | 0.2 |

Table 5. Decision Matrix

| | Machine Failures and Lack of Maintenance | Inadequate Training and Awareness | Electrical Hazards | Inadequacy or Lack of Machine Guards | Difficult Working Conditions |
|---|---|---|---|---|---|
| Regular Maintenance and Inspection | 9 | 9 | 8 | 8 | 7.333 |
| Training Programs and Awareness | 8.333 | 8.333 | 8.667 | 8.667 | 8.333 |
| Electrical Safety Precautions | 8 | 9 | 9 | 8.667 | 8.333 |
| Use of Machine Protective Equipment | 8 | 8.333 | 8 | 9.667 | 7.333 |
| Establishment of Safe Working Procedures | 9.333 | 7.667 | 8.666 | 9.333 | 9 |

Table 6. Normalized Matrix

| | Machine Failures and Lack of Maintenance | Inadequate Training and Awareness | Electrical Hazards | Inadequacy or Lack of Machine Guards | Difficult Working Conditions |
|---|---|---|---|---|---|
| Regular Maintenance and Inspection | 0.471 | 0.475 | 0.422 | 0.403 | 0.405 |
| Training Programs and Awareness | 0.436 | 0.439 | 0.457 | 0.436 | 0.461 |
| Electrical Safety Precautions | 0.418 | 0.475 | 0.475 | 0.436 | 0.461 |
| Use of Machine Protective Equipment | 0.418 | 0.439 | 0.422 | 0.487 | 0.405 |
| Establishment of Safe Working Procedures | 0.488 | 0.404 | 0.457 | 0.47 | 0.497 |

Table 7. Weighted Normalized Matrix

| | Machine Failures and Lack of Maintenance | Inadequate Training and Awareness | Electrical Hazards | Inadequacy or Lack of Machine Guards | Difficult Working Conditions |
|---|---|---|---|---|---|
| Regular Maintenance and Inspection | 0.118 | 0.142 | 0.084 | 0.101 | 0.081 |
| Training Programs and Awareness | 0.109 | 0.132 | 0.091 | 0.109 | 0.092 |
| Electrical Safety Precautions | 0.105 | 0.142 | 0.095 | 0.109 | 0.092 |
| Use of Machine Protective Equipment | 0.105 | 0.132 | 0.084 | 0.122 | 0.081 |
| Establishment of Safe Working Procedures | 0.122 | 0.121 | 0.091 | 0.117 | 0.099 |

Table 8. Positive and Negative Ideal Solutions

| | Positive ideal | Negative ideal |
|---|---|---|
| Machine Failures and Lack of Maintenance | 0.122 | 0.105 |
| Inadequate Training and Awareness | 0.142 | 0.121 |
| Electrical Hazards | 0.095 | 0.084 |
| Inadequacy or Lack of Machine Guards | 0.122 | 0.101 |
| Difficult Working Conditions | 0.099 | 0.081 |

Table 9. Distance to Positive and Negative Ideal Points

| | Distance to positive ideal | Distance to negative ideal |
|---|---|---|
| Regular Maintenance and Inspection | 0.03 | 0.025 |
| Training Programs and Awareness | 0.023 | 0.019 |
| Electrical Safety Precautions | 0.023 | 0.027 |
| Use of Machine Protective Equipment | 0.029 | 0.023 |
| Establishment of Safe Working Procedures | 0.022 | 0.031 |

Table 10. Ci Value and Ranking

| | Ci | rank |
|---|---|---|
| Regular Maintenance and Inspection | 0.451 | 4 |
| Training Programs and Awareness | 0.461 | 3 |
| Electrical Safety Precautions | 0.546 | 2 |
| Use of Machine Protective Equipment | 0.444 | 5 |
| Establishment of Safe Working Procedures | 0.589 | 1 |

Figure 1 shows the $c_i$ values.

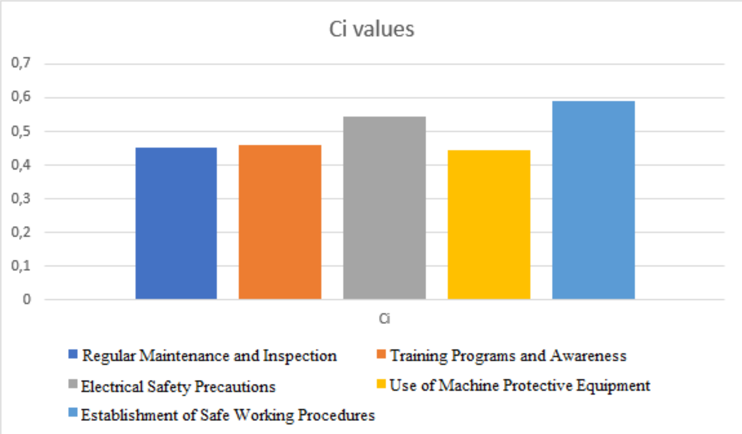



Figure 1. Ci Values

## 4. Discussion and Conclusion

The findings of the study reveal the effectiveness of HRNS and TOPSIS methods in the management and prevention of machine-based risks in forestry transportation works. While the HRNS method allows for the systematic evaluation and ranking of hazards and risks, the TOPSIS method plays a critical role in determining the most appropriate measures against these risks. The use of these two methods together brings a multidimensional approach to the risk assessment process, allowing for more comprehensive and reliable results.

The HRNS Method addresses the risk of machines used for transportation. With the TOPSIS Method, a more effective solution has emerged in calculating the best alternatives for these identified risks, that is, the criteria and weights of risks and decision makers. When the alternatives are ranked according to the magnitude of their proximity coefficients, it is seen that the most appropriate alternative measure for the risks is “Establishing Safe Working Procedures”. Then, the alternatives of “Electrical Safety Measures”, “Education Programs and Awareness”, “Regular Maintenance and Inspection” and “Use of Machine Protective Equipment” are listed respectively. The best alternative method for the specified risks, the “Establishing Safe Working Procedures” alternative, is the most successful tool against these threats. It is also seen that the values of the alternatives differ slightly between them.

The HRNS method plays an important role in providing appropriate equipment according to the risk level of the hazard. In other words, the parameters of the HRNS values of the equipment are calculated. Similar to these methods, Fine-Kinney, FMEA, MIL-STD-882 series calculate the probability of risks such as HRNS calculation. Using the TOPSIS method, more reasonable alternatives can be selected and corresponding measures can be applied against the identified risks. Especially in machine-based risk assessment studies, more accurate alternative measures can be listed using this method. In addition, the best solution can be calculated. Another important contribution of the study is based on a comprehensive analysis of the measures proposed to reduce occupational accidents in the forestry sector. In particular, the determination of the "Establishment of Safe Working Procedures" alternative as the most appropriate solution emphasizes how important such procedures are in increasing the safety of employees. The establishment and implementation of safe working procedures stands out as a critical factor in preventing occupational accidents and contributes to the development of a safety culture throughout the sector (Çalışkan et. al., 2012).

However, the findings of the study also reveal that more factors should be taken into account in the risk assessment of machines used in forestry transport works. For example, external factors such as environmental factors, climatic conditions and ground condition of the work area can also be considered as important elements affecting machine safety and risk level. Consideration of such factors can increase the accuracy and validity of the risk assessment process (Varol et. al., 2020; Eser, 2019). In addition, this study shows that risk assessment methods are a dynamic and continuous process. The methods and measures used in the management of machine-based risks need to be constantly reviewed and updated. With the emergence of new technologies and safety standards, the effectiveness of existing methods should also be re-evaluated. In this context, the continuous development of research and applications will be an important step towards improving occupational health and safety. In conclusion, this study provides an important perspective on the management of machine-based risks in transport operations in forestry and provides a solid basis for future research. It is possible to further develop risk assessment processes, especially with the integration of different methods and technologies. Such studies will provide valuable contributions not only to the forestry sector but also to other industries that require the use of machinery.

**References**

Acar H. H. (2017). Orman İçinde Tomruk Transportu İçin Bir Mini Hava Hattı AcarMHH300 Sistemi Geliştirilmesi, Turkish Journal of Forestry, 18(3), 226–231.

Akgül M., Esin A.İ., Akay A.O., Şentürk N., Acar H.H. (2021). Türkiye de Ormancılık Sektöründe Meydana Gelen İş Kazalarının Değerlendirilmesi, Bartın Orman Fakültesi Dergisi 23, 2, 614–623.

Akkoyun Ö., Ekinci G. (2021). Farklı İSG Risk Değerlendirme Yöntemlerinin Bir Yeraltı Maden İşletmesinde Karşılaştırmalı Uygulanması Ve Yöntem Önerisi. Bilimsel Madencilik Dergisi, 60(4), 219-226.

Bilir S., Gürcanlı G.A. (2017). İnşaatlarda Yeni Bir Risk Değerlendirme Yöntemi: HRNS. İşçi Sağlığı ve İş Güvenliği Sempazyomu, İstanbul.

Cheng-Min F., Wang R.T. (2001). Considering the Financial Ratios on The Performance Evaluation of Highway Bus Industry, Transport Reviews, Vol.21, No.4, p.449-467.

Ching-Shih T. (2008). Multi-Objective Inventory Planning Using MOPSO and TOPSIS, Expert Systems with Applications 35, p.136-142.

Çalışkan E., Acar H.H. (2012). A Simulated Annealing Approach to Problems of the Transportation of Wood Raw Material, Advances in Intelligent Transportation Systems 2, 1, 110–117.

Eser F. (2019). Mobilya Üretimi Yapılan İşyerlerinde İş Sağlığı ve Güvenliği ile İlgili Bir Alan Araştırması. Kahramanmaraş: Sütçü İmam Üniversitesi Fen Bilimleri Enstitüsü.

Madi E. N., Garibaldi J. B., Wagner C. (2015). A comparison between two types of Fuzzy TOPSIS Method, IEEE.

Özkılıç O. (2005). Occupational Health and Safety and Risk Assessment Methods. TISK, Istanbul, Turkey. (In Turkish).

Silvestri A., De Felice F., Petrillo A. (2012). Multi-Criteria Risk Analysis to Improve Safety in Manufacturing Systems, International Journal of Production Research, 50(17).

Soba M., Eren K. (2011). Performance Evaluation According to Financial and Non-Financial Ratios Using the TOPSIS Method, An Application In The Intercity Bus Sector" Journal of Social Economic Research, Vol.21 p23-40.

Varol T., Emir T., Akgül M., Özel H.B., Acar H.H., Çetin, M. (2020). Impacts of Small-Scale Mechanized Logging Equipment on Soil Compaction in Forests, Journal of Soil Science and Plant Nutrition 20, 3, 953–963.

# Determination of Soil Deformation with Unmanned Aerial Vehicles in Logging Activities with Agricultural Tractors

**Ebru Bilici[1,2*], Halit Büyüksakallı[3], Abdullah Emin Akay[4]**

[1]University of Idaho, Experimental Forest, College of Natural Resources, Moscow, ID, USA
[2]Giresun University, Dereli Vocational School, 28902 Giresun, Türkiye
[3]Muğla Sıtkı Koçman University, Köyceğiz Vocational School, 48000 Muğla, Türkiye
[4]Bursa Technical University, Faculty of Forestry, 16310 Bursa, Türkiye
ebilici@uidaho.edu

**Abstract**
Mechanical timber extraction system provides higher quality products and safer working environment than traditional timber extraction system (Manpower and Animal power). However, if the logging work is not planned properly, mechanical production tools cause damage to the trees and saplings left in the stand, and heavy logging equipment with rubber wheels and pallets can damage the physical properties of the forest soil. The products skidded on the ground during the extraction work carried out using mechanical tools cause various deformations on the forest soil. Some of these damages are soil compaction, rut depth, losses in soil fertility and nutrient content, erosion due to surface runoff, and destruction of the humus layer. Rut depths, which are an important soil deformation indicator, can be effectively determined by using digital surface models produced with the help of UAV. This study was carried out in Yeniköy Forest Management Directorate to determine the soil deformation that occurred during removal from the compartment with an agricultural tractor using UAV. In the study, three autonomous flights (Control, 10$^{th}$ trip, 20$^{th}$ trip,) were made with the UAV, and rut depths and soil volume losses were determined from the high-resolution images obtained using Agisoft PhotoScan software. In addition, local rut depths of the study area were measured with a manual method (ruler method) at 10 meter intervals. The rut depths measured by UAV and the rut depths measured by the manual method were compared with the Paired Sample T-Test in the SPSS 20 program. As a result, it was determined in the study that rut depths increased as the number of trips increased and soil deformation increased similarly.

***Keywords:*** *Skidding, UAV, soil deformation, wheel rut depth*

## 1. Introduction

Mechanical logging systems provide higher quality products and safer working environments than traditional logging systems (Akay and Erdaş, 2007). However, if logging activities are not planned appropriately, mechanized harvesting equipment can cause damage to residual trees and saplings left in the stand. Besides, heavy equipment with rubber tires and tracks can damage the physical properties of the forest soil (Heninger et al., 2002; Erdaş, 2008; Eroğlu, 2012).

During the logging activities carried out using mechanized equipment, forest soil can be damaged by the equipment and the products skidded on the ground. Some of these damages are soil compaction, rut depth, losses in soil fertility and nutrient content, erosion due to surface runoff and destruction of the humus layer (Ballard, 2000; Eroğlu, 2012). The amount and severity of damage to the forest soil during logging activities vary depending on the equipment used in logging, the intensity of the operation, the slope of the land and the soil properties (Heninger et al., 2002). The rut depths caused by mechanized equipment during the extraction of forest products can be evaluated using high-resolution images. Using digital surface models to be produced with the help of UAV, rut depth, which are an important soil deformation indicator, can be effectively determined (Pierzchała et al., 2014). There are limited and few studies examining the rut depths caused by mechanized equipment on forest soil using UAV images (Yurtseven et al., 2016; Aydın et al., 2019).

In this study, it was aimed to determine the deformation on the forest soil by using UAV during a tractor logging operation, which is one of the commonly used method in Türkiye. Digital Surface Model and Orthophoto map were produced from the images obtained by a UAV. Then, rut depth and volumetric changes were calculated using UAV data and it was compared with the results obtained by ground measurements.

## 2. Material and Methods

### 2.1. Study Area

The study area is in Yeniköy Forestry Enterprise Chief (FED) located in Bursa Regional Directorate of Forestry (FRD). The forest area of Yeniköy FED is 11,143 hectares. The location of the study area is shown in Figure 1.


Figure 1. Study area

In this study, images were taken for the production of Digital Elevation Model (DEM) with UAV to determine soil deformation in Fiat 60-56 agricultural tractor. Technical specifications of the agricultural tractor are given in Table 1 (Figure 2).

Table 1. Technical specifications of Fiat 60-56 agricultural tractor

| Specifications | Values |
|---|---|
| Length | 3200 mm |
| Front tire trace width | 1435mm |
| Front tire trace width | 1435-1935mm |
| Height above ground | 380 mm |
| Weight | 2490 kg |
| Engine | 60 hp |
| Engine capacity | 2931 cc |

Figure 2. Fiat 60-56 Agricultural Tractor used during logging in Yeniköy FEC

In order to determine soil deformation in the study area, a flight was made with the UAV by selecting the single grid flight mode (Grid Mission) using the Pix4d software before the agricultural tractor entered the area. In this flight, the flight altitude was determined as 70 m, forward and lateral overlap rates were 80% and 70%, respectively, flight speed was determined as medium level and the flight area dimension was 150 m x 50 m. Depending on these settings, the flight duration was calculated as 6 minutes. Images of the Pix4d program flight information are given in Figure 3.

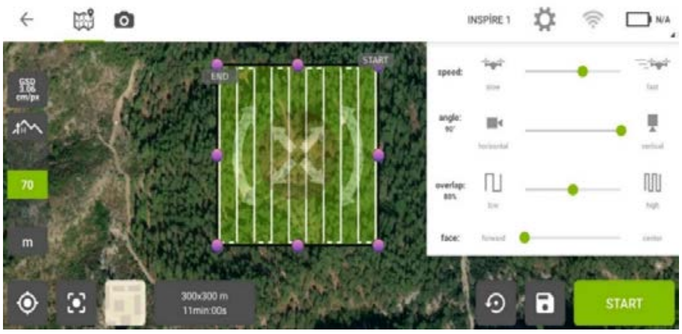



Figure 3. Pix4d flight settings screen

The study area had a gentle slope. Cross-sections were taken every 10 m from the DEMs obtained in study area. The length of the skid road in the study area was 160 m and rut depths were taken from 15 points (Figure 4). From these cross-sections, wheel track depths were measured locally in the study area with the ruler method and these depths were compared with the data obtained with the UAV. SPSS program was used in this comparison and Paired Sample T-Test was used to investigate whether there was a statistically significant difference between the wheel track depth measurements made with the UAV and ruler method.

Figure 4. Plan view of 15 cross sections produced along the skid road

## 2.2. Agisoft PhotoScan Processes

The images taken by the UAV first start with the generation of connection points (Align Photos) by taking the photos to the program interface. After this process, tie points (Tie

Points) were produced on the interface. This stage was followed by verification processes carried out with 6 ground control points taken from the study area. Then, by right-clicking on the ground control point, the aerial photos covering the area where the selected ground control point is located were filtered with the "Filter by Photos" process. The centers of the ground control points seen in these photos were moved to the correct points. This process was applied to all ground control points. In order for all photos to be placed in the correct positions, the "Optimize Cameras" process was used to overlap the photos located in the same region with the ground control point centers. In the stage following the correction processes, the connection points were used to produce "Dense Cloud" (dense point cloud). Then, the DEM of the study area was produced using the "Build DEM" process. In the last stage, the Build Orthomosaic process was applied for orthophoto production.


Figure 5. Orthophoto images used in determining soil deformation of the operations at control (above), 10th trip (middle), and 20th trip (below)

## 3. Results and Discussion

### 3.1. Agisoft PhotoScan Results

The images obtained by the UAV from the study area were processed by the Agisoft PhotoScan program and the data were evaluated separately in the Control, 10th and 20th trips (Table 2). For each group following parameters were recorded; the number of images obtained by the UAV, the number of GCPs, the number of Tie Points, the number of points in the point cloud, the DEM resolution, and the Ortamosaic resolution.

Table 2. Data obtained by Agisoft PhotoScan

| | Control | 10th trip | 20th trip |
|---|---|---|---|
| The number of images | 54 | 53 | 54 |
| The number of GCPs | 6 | 6 | 6 |
| The number of tie points | 214 786 | 277 283 | 163 421 |
| The number of points in the point cloud | 5 557 138 | 11 512 992 | 11 106 150 |
| DEM resolution | 3.28 cm/pix | 3.13 cm/pix | 3.23 cm/pix |
| Ortamosaic resolution | 1.63 cm/pix | 1.57 cm/pix | 1.61 cm/pix |

### 3.2. Findings Regarding Rut Depths

The rut depths obtained with two methods for the 10th and 20th trips are given in Table 3. According to the data obtained with UAV, the left wheel track depth was found to be 5.47 cm on average in the 10th trip and 5.40 cm for the ruler method, and the average rut depth for the 20th trip was found to be 6.30 cm for UAV and 6.51 cm for the ruler method. When rut depths were taken into account, the rut depth was found to be 5.89 cm for UAV and 5.96 cm for the ruler method.

Table 3. Rut depths obtained with two methods for the 10th and 20th trips (cm)

| | Left Tire | | Right Tire | | Left Tire | | Right Tire | |
|---|---|---|---|---|---|---|---|---|
| | UAV | Ruler | UAV | Ruler | UAV | Ruler | UAV | Ruler |
| 1 | 4.5 | 4.1 | 3.5 | 3.3 | 4.8 | 5.2 | 3.6 | 3.5 |
| 2 | 4 | 4.2 | 2.9 | 2.7 | 4.2 | 5.4 | 3.3 | 3 |
| 3 | 2.3 | 2.6 | 3.7 | 3.9 | 2.8 | 3.2 | 3.7 | 4 |
| 4 | 5 | 5.8 | 2.8 | 2.6 | 6.2 | 7.1 | 3.8 | 3.6 |
| 5 | 3 | 3.2 | 1.5 | 1.8 | 3.2 | 3.8 | 2.6 | 2.8 |
| 6 | 2.9 | 3.1 | 2.3 | 2.6 | 6.1 | 5.8 | 3.4 | 4 |
| 7 | 2.7 | 2.8 | 3.1 | 2.7 | 3.2 | 3.8 | 3.8 | 3.6 |
| 8 | 3.8 | 3.6 | 4.5 | 3.5 | 4.2 | 4.2 | 5.2 | 4.7 |
| 9 | 6 | 5.8 | 3.1 | 3.8 | 6.6 | 5.6 | 3.6 | 4.2 |
| 10 | 5.1 | 5.4 | 5.4 | 5 | 6.1 | 6.8 | 5.8 | 6.2 |
| 11 | 10 | 9.8 | 8.3 | 8 | 10.8 | 10.5 | 9.3 | 9.6 |
| 12 | 16.6 | 15.6 | 10.5 | 10 | 18.2 | 17.2 | 11.5 | 12.5 |
| 13 | 4.1 | 3.6 | 14.7 | 14.5 | 4.8 | 4.6 | 16.7 | 15.9 |
| 14 | 4.2 | 4.8 | 2.8 | 2.6 | 5.2 | 6.2 | 3.6 | 3.8 |
| 15 | 13.9 | 13.5 | 7 | 7.2 | 14.6 | 14.8 | 8.2 | 9.6 |

In the study, within the scope of statistical analyses, Descriptive Statistics and Normal Distribution Test were performed to check the normal distribution of the data. The descriptive statistics obtained for the 10th and 20th trips are given in Tables 4. When the results were examined, it iwas seen that the Skewness and Kurtosis values were between -3 and +3 according to the descriptive statistics values, therefore, they are suitable for normal distribution (Tabachnick and Fidell, 2013; Ross and Willson, 2018).

Correlation Analysis was first performed to examine the relationship between 30 rut depth data obtained by UAV and ruler method (Table 5). In the next step, Paired T-Test was applied to understand whether there was a significant difference between the two groups (Table 6). According to the correlation analysis results, the value of 0.995 was found in the 10th trip and 0.989 in the 20th trip. Since this value is very close to 1, it is seen that there is a strong positive relationship between the measurements. When the results of the paired sample T-Test conducted in the next stage are taken into consideration, the significance value (significance) was found to be 0.533 and since it is greater than 0.05, it was revealed that there was no significant difference between the measurements. Therefore, there is a similarity between the UAV and ruler method measurements conducted after the 10th trip.

Table 4. Descriptive statistics of measurements made with UAV and ruler method

| | | | 10th Trip | | 20th Trip | |
|---|---|---|---|---|---|---|
| | | | Statistic | Std. | Statistic | Std. |
| UAV | Mean | | 5.4733 | 0.71327 | 6,3033 | 0,75691 |
| | 95% Confidence Interval for Mean | Lower | 4.0145 | 4.7553 | 4.7553 | |
| | | Upper | 6.9321 | 7.8514 | 7.8514 | |
| | 5% Trimmed Mean | | 5.0963 | | 5.8722 | |
| | Median | | 4.0500 | | 4.8000 | |
| | Variance | | 15.263 | | 17.187 | |
| | Std. Deviation | | 3.90675 | | 4.14575 | |
| | Minimum | | 1.50 | | 2.60 | |
| | Maximum | | 16.60 | | 18.20 | |
| | Range | | 15.10 | | 15.60 | |
| | Interquartile Range | | 3.35 | | 3.40 | |
| | Skewness | | 1.684 | 0.427 | 1.712 | 0.427 |
| | Kurtosis | | 2.051 | 0.833 | 2.220 | 0.833 |
| Ruler method | Mean | | 5.4033 | 0.67980 | 6.5067 | 0.72891 |
| | 95% Confidence Interval for Mean | Lower | 4.0130 | 5.0159 | 5.0159 | |
| | | Upper | 6.7937 | 7.9975 | 7.9975 | |
| | 5% Trimmed Mean | | 5.0426 | | 6.1389 | |
| | Median | | 3.8500 | | 4.9500 | |
| | Variance | | 13.864 | | 15.939 | |
| | Std. Deviation | | 3.72341 | | 3.99240 | |
| | Minimum | | 1.80 | | 2.80 | |
| | Maximum | | 15.60 | | 17.20 | |
| | Range | | 13.80 | | 14.40 | |
| | Interquartile Range | | 3.38 | | 3.93 | |
| | Skewness | | 1.642 | 0.427 | 1.522 | 00.427 |
| | Kurtosis | | 1.854 | 0.833 | 1.393 | 0.833 |

Table 5. Correlation analysis results for UAV and ruler method for the 10th and 20th trips

| | | UAV | Ruler |
|---|---|---|---|
| UAV - Ruler 10th trip | Pearson Correlation | 1 | 0.995 |
| | Sig. (2tailed) | | 0.00 |
| | N | 30 | 30 |
| UAV - Ruler 20th trip | Pearson Correlation | 0.989** | 1 |
| | Sig. (2tailed) | 0.00 | |
| | N | 30 | 30 |

Table 6. Paired sample T-Test results for UAV and ruler method for the 10th and 20th trips

| | 95% Confidence Interval of the Difference | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2tailed) |
| IHA&Ruler 10 | 0.7 | .43403 | .07924 | -.09207 | .23207 | .883 | 29 | .384 |
| IHA&Ruler 20 | -.20333 | .61503 | .11229 | -.43299 | .02632 | -1.811 | 29 | .081 |

**3.3. Volume Results**

The volumetric deformation that occurred during the logging performed with an agricultural tractor was determined using UAV data. The measurements were made after the 10th and 20th trips. The amount of increase in volumetric deformation that occurred in the 20th trip compared to the 10th is given in Table 7. According to the results, it was determined that there was a greater increase in the 20th trip when the unit deformation was taken into account. Previous studies have also stated that there is a positive correlation between soil deformation and the number of rounds (Sugden and Woods, 2007; Büyüksakallı, 2023).

Table 7. Increase in volume deformation in the 20th trip compared to the 10th trip

| | 10th trip | 20th trip |
|---|---|---|
| Total deformation | 1.685 $m^3$ | 4.124 $m^3$ |
| Unit deformation | 0.011 $m^3/m$ | 0.026 $m^3/m$ |

Figure 6. Areas with wheel tracks along the skid path

**4. Conclusion**

In order to ensure the sustainability of the advantages offered by mechanized logging equipment to users producing forest products, the ecological and economic disadvantages caused by deep ruts must be eliminated or reduced to acceptable limits. Therefore, if a choice is to be made between logging equipment, the logging method should be planned accordingly, considering the damage this equipment will cause to the forest soil. According to this plan, the most appropriate logging method and equipment should be preferred. UAV data can be used to evaluate the rut depths caused by mechanized logging during the extraction of forest products using high-resolution images. In this study, high-resolution images were taken with UAV and the deformation caused by the agricultural tractor on the forest soil was evaluated. The deformation caused by the agricultural tractor to the forest soil was determined as rut depth and soil volume displacement. It was observed that the rut depths determined by UAV images were very similar to the depths measured with a ruler. It was determined that there was a positive relationship between the deformation formed in the soil and the number of trips, and it was found that the deformation increased as the number of trips increased. It is thought that this study will enable appropriate production planning by determining in advance the possible environmental effects of mechanized logging equipment used, especially in terms of soil deformation.

**References**

Akay, A.E., Erdaş, O. 2007. Estimating rut depth during skidding with a rubber tired skidder. SDU Faculty of Forestry Journal, 2007(1): 49-57.

Aydın, A., Türk, Y., Eker, R. 2019. Pros and cons of the manual and autonomous UAV flights in mapping of the forest road surface deformations: preliminary results, 2nd International Symposium of Forest Engineering and Technologies, 04-06 September, Tirana, Albania.

Ballard, T.M. 2000. Impacts of forest management on northern forest soils, Forest Ecology and Management, 133: 37-42.

Büyüksakallı, H. 2023. Using digital images obtained from an unmanned aerial vehicle for evaluating productivity and soil deformation of mechanized harvesting equipment. (Phd thesis). Bursa Technical University, Bursa.

Erdaş, O. 2008. Transportation Techniques Text Book. KSÜ Rectorate, Kahramanmaraş, 130/20, 554.

Eroğlu, H. 2012. Effects of Different Logging Techniques on Forest Soil Compaction at Mountainous Terrain, Artvin Çoruh University Faculty of Forestry Journal, 13(2): 213-225.

Heninger, R., Scott, W., Dobkowski, A., Miller, R., Anderson, H., Duke, S. 2002. Soil disturbance and 10-year growth response of coast douglas-fir on non-tilled and tilled skid trails in the oregon cascades, Canadian Journal of Forest Research, 32(2), 233-246.

Pierzchała, M., Talbot, B., Astrup, R. 2014. Estimating soil displacement from timber extraction trails in steep terrain: application of an unmanned aircraft for 3d modelling, Forests, 5, 1212-1223.

Ross, A., Willson, V.L. 2018. Basic and advanced statistical tests: Writing results sections and creating tables and figures. Springer, Netherlands

Sugden, B.D., Woods, S.W. 2007. Sediment Production from Forest Roads in Western Montana 1, JAWRA Journal of the American Water Resources Association, 43(1), 193–206.

Tabachnick, B.G., Fidell, L.S. 2013. Using multivariate statistics (6th ed.). Boston: Pearson. Boston, USA. 983 s.

Thawornwong, L. 2006. The effect of skidtrial curves on soil loss in a selectively harvested dipterocarp forest in east Kalimantan, Indonesia, Center for International Forestry Research (CIFOR), Jakarta, Indonesia, 19-21.

Yurtseven H., Demir M., Akgül M., Akay A.O. 2016. Comparison of drone based photogrammetry and terrestrial laser scanning for forest road surface modeling, 1st International Symposium of Forest Engineering and Technologies (FETEC 2016), Bursa, Turkey:02-04 Haziran.

# Redesigning Administrative Measures on Wildlife: Case Study of Deer Management in Kumamoto Prefecture, Japan

**Junna Iwano[1*], Noriko Sato[2], Takahiro Fujiwara[2]**

[1] Kyushu University, Graduate School of Bioresource and Bioenvironmental Sciences, Fukuoka 819-0395, Japan
[2] Faculty of Agriculture, Kyushu University, Fukuoka 819-0395, Japan
*iwano.junna.080@s.kyushu-u.ac.jp

**Abstract**

Deer (*Cervus nippon*)-induced forest damage is a pressing issue in Japan, yet the division of responsibilities for deer capture remains unclear. Considering the situation where reforestation is being prevented by deer damage, the position of local hunters in forest management and wildlife management is an important issue. This study aims to explore the roles of hunters at the local government level and examine the relationship between local government officials and hunters. The study was conducted in Yamae and Kuma Villages, both located in Kumamoto Prefecture, a major forestry region where deer-related forest damage is severe. We conducted interviews with local government staff and leaders of hunting clubs in these villages. The interviews highlighted both differences and commonalities between the two villages. While the organisational structure of hunting teams varied, there were shared trends in shifting attitudes towards hunting and hunting practices. Comparing each area at a local level and organizing the differences and commonalities could provide insight for local governments to redesign wildlife management in the future.

***Keywords:*** *Wildlife management, deer, forest management, rural communities, Japan*

## 1. Introduction

In recent years, Human-Wildlife Conflict (HWC) has become a global issue. Various incidents are classified as HWC, such as damage to agriculture and forestry, traffic accidents, human injury, and zoonotic diseases. In Japan, typical examples of wildlife involved in these conflicts include deer, wild boars, and monkeys. In forestry, damage caused by deer is particularly severe.

In Japan, the area of forest damaged by wildlife in 2022 was 4,640 hectares, with deer accounting for approximately 70% of this damage (Figure 1). Damage caused by deer reduces the motivation for forest management and impacts the ecosystem (Côté et al., 2004). In Japan, where heavy rain disasters have become increasingly frequent in recent years, the risk of landslides due to the loss of understory vegetation is a significant concern. The Ministry of the Environment set a target to halve the deer population by 2023. However, this target proved difficult to meet, and the deadline was extended to 2028 (Ministry of the Environment, 2023).

Hunters play a crucial role in reducing deer populations. However, in recent years, the number of hunters has declined, and the hunting population has aged. This trend is common in several Northern Hemisphere countries, for example in Norway (Andersen et al., 2010), Sweden (Hansson-Forman et al., 2020), Denmark (Hansen et al., 2012), and America (Ryan et al., 2011) but is especially pronounced in Japan, where, as of 2018, more than half of the hunters were aged 65 or older (Figure 2).

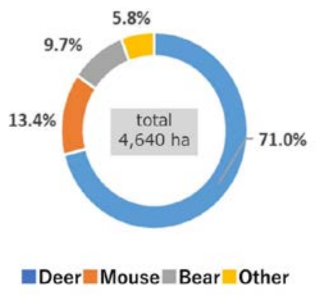



Figure 1. Forest damage caused by major wildlife in FY2022. Source: Prepared by the author using data from the Forestry Agency website (2024)

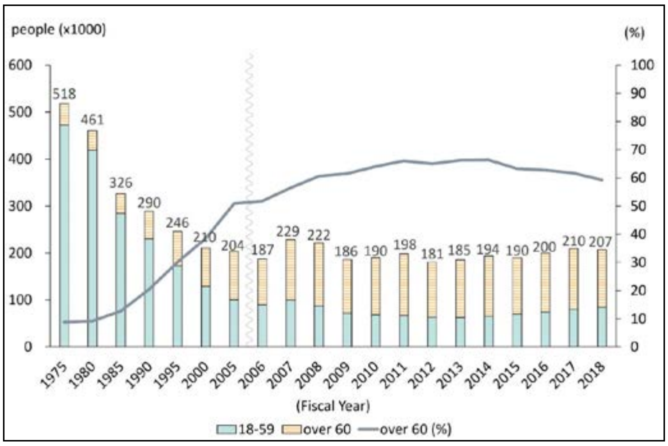



Figure 2. Trends in the number of hunters in Japan. Source: Prepared by the author using data from the Ministry of the Environment website

Given these circumstances, many studies have been conducted on hunters (Makino et al., 2018; Lovelock et al., 2021). Several questionnaire surveys have been conducted to investigate status and attitudes of hunters (Tsunoda et al., 2016; Mitani et al., 2018). However, except for the study by Takeyama et al. (2017), most of this research has been conducted at the prefectural level.

Japan has two primary deer management plans: the Specified Wildlife Management Plan, prepared at the prefectural level, and the Damage Control Plan, prepared at the municipal level. Local hunters are also key players in deer management. To make Damage Control Plans more locally adaptable, it is essential to understand the situation of hunters at the municipal level. Takeyama et al. (2017) highlighted the need to understand local-level hunting recruits, such as within municipalities. Furthermore, while there are previous studies on how the two plans harmonise between prefectures and municipalities (Ikoma, 2024), there is no research on how relationships are formed between local hunters and local governments. Therefore, this study has two objectives: to gain a detailed understanding of hunters' circumstances at the local government level and to clarify the nature of the relationships established between local government staff and local hunters.

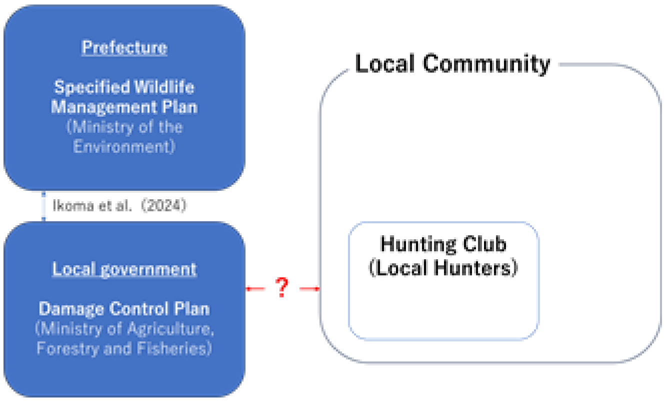



Figure 3. The framework of this paper

## 2. Materials and Methods

### 2.1 Materials

This survey targeted two villages in Kumamoto Prefecture: Yamae Village and Kuma Village. Kumamoto Prefecture was one of the leading timber-producing regions in Japan. In Kyushu, the estimated deer population had remained stable despite an increase in the number of deer harvested (Suzuki et al., 2022), but further increases in hunting pressure were required. The Kuma River Basin, where Yamae and Kuma were situated, was an area where deer had historically been hunted (Yasuda, 2024), and the estimated deer population remained high in this region (Kumamoto Prefecture, 2019).

### 2.2 Methods

This study involved collecting administrative data from a website and conducting interviews. Interviews were held with several local government officials and leaders of hunting clubs in both villages.

## 3. Results and Discussion

### 3.1 Basic information on both villages

The basic data for both villages are shown in the table below. In 2020, heavy rainfall severely damaged both villages, leading to a population outflow, with the rate of population decline being particularly high in Kuma Village.

### 3.2 Differences between the two villages

Comparing the two villages, notable differences in the structure of the hunting staff emerged. In Kuma Village, a council had been established in 2010, and a meat-processing plant was built in 2011. At the time of the study, the village employed one person from another prefecture as local staff for hunting and gibier. This individual played a key role in promoting the use of deer as meat, and in 2023, 492 deer were brought to the plant. Approximately 90% of these were hunted using traps, while 10% were hunted with guns. Deer were bought from hunters for 2,000 yen each, and the number of deer transported to the factory had increased annually. An interesting aspect was the discussion surrounding transport methods. The leader of the hunting club in Kuma Village remarked, “I think there should be a financial subsidy for installing a winch on a light truck to transport captured deer.”

Table 1. Data for both villages

| | Yamae | Kuma |
|---|---|---|
| Population (people) | 3,057 | 1,844 |
| Area (ha) | 12,119 | 20,758 |
| Forest Area (%) | 87% (10,510 ha) | 88% (18,187ha) |
| Main industries | Forestry, Agriculture | Forestry, Agriculture |
| Number of hunting club members (people) | 43 | 50 |
| Average for hunting club members (age) | 67.6 | -- (32 are aged 65 or over) |
| Number of deer captured | 1,043 (in 2023) | 1,128 (in 2021) |

In Yamae Village, forestry department staff had actively acquired hunting licences and participated in hunting clubs. At the time of the study, five staff members were involved in hunting. The staff raised concerns about financial strain. In both villages, a reward of 10,000 yen was given for each deer captured. However, this applied only if a deer was successfully hunted. Hunting incurred costs such as petrol and equipment, and it took time to check trap sites. Considering the financial and time investment required, it was necessary to reassess whether the reward was sufficient.

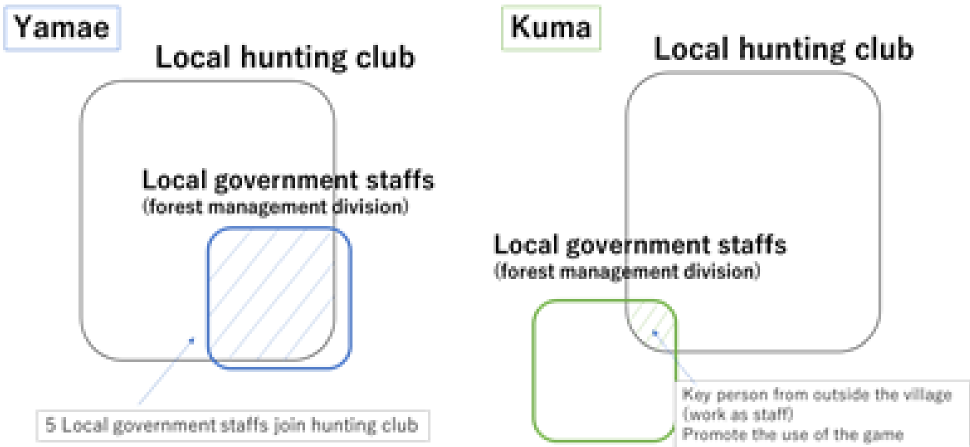



Figure 4. Differences between the two villages

Table 2. The reward for deer capture.

| Source | Reward |
|---|---|
| National | ¥7,000 (€44.57) / per deer |
| Prefecture | ¥1,000 (€6.37) / per deer |
| Village | ¥2,000 (€12.73) / per deer |
| Total | ¥10,000 (€63.67) / per deer |

### 3.3 Similarities between the two villages

Both villages exhibited similarities in their changing attitudes towards hunting. Local hunting club leaders noted that, while hunting had once been considered a leisure activity, it had become a community obligation. This reflected a shift towards the social and compulsory aspects of hunting. Moreover, trap hunting was increasing across Japan, and this trend was evident in both villages.

### 3.4 Limitations and future prospects

When comparing the two villages, despite their proximity, differences in the structure of local staff and the relationship between government officials and hunters became evident. The focus will be on how the policies of the two villages will differ in the future. In both villages, changes in hunting practices had become noticeable. Given these changes, it was important to manage forests and maintain roads to make hunting more accessible. In future studies, we will quantify the financial and temporal pressures experienced by hunters and reconsider the roles of local governments, communities, and individuals. Additionally, it will be important to explore what hunters find enjoyable about the activity and the differences between gun hunting and trap hunting.

### References

Andersen, O., Vittersø, J., Kaltenborn, B. P., Bjerke, T. 2010. Hunting Desertion in Norway: Barriers and Attitudes Toward Retention Measures. Hum. Dimen. Wildl. 15(6): 450-466. DOI: 10.1080/10871209.2010.510498

Forestry Agency. 2024. Forest damage caused by major wildlife in FY2022. https://www.rinya.maff.go.jp/j/hogo/higai/tyouju.html (accessed October 22, 2024). [in Japanese].

Hansen, H. P., Peterson, M. N., Jensen, C. 2012. Demographic Transition Among Hunters: A Temporal Analysis of Hunter Recruitment Dedication and Motives in Denmark. Wildl. Res. 39(5): 446-451. DOI: 10.1071/WR12028

Hansson-Forman, K., Sandström, C., Ericsson, G. 2020. What Influences Hunting Participation of Potential New Hunters? Qualitative Insights from Sweden. Wildl. Biol. 4: 1–9. DOI: 10.2981/wlb.00721

Ikoma, S., Owake, T., Onda, N., Fujiwara, T. 2024. The enforcement system for “Category 2 Specified Wildlife Protection Plan” for sika deer and its issues in Nagasaki: Focusing on consistency with the Damage Prevention Plan and cooperation between prefectural and city governments. Kyushu Journal of Forest Research. 77: 53-60. [in Japanese].

Kumamoto Prefecture. 2020. FY2019 Kumamoto Prefecture Deer Habitat Survey Report. https://www.pref.kumamoto.jp/uploaded/attachment/108574.pdf (accessed October 22, 2024). [in Japanese].

Lovelock, B., Yanata, K., Seto, Y., Yamaguchi, M. 2022. Societal Factors Influencing Hunting Participation Decline in Japan: An Exploratory Study of Two Prefectures. Society & Natural Resources. 35(2): 149-166. DOI: 10.1080/08941920.2021.2006843.

Makino, S., Hattori, T. 2018. The actual conditions of the support system after hunting license acquisition. Water, Land and Environmental Engineering. 86(5): 399-402. DOI: 10.11408/jjsidre.86.5_399. [in Japanese].

Ministry of the Environment. 2023. Regarding reinforced capture measures and capture goals for deer and wild boar. https://www.env.go.jp/nature/choju/effort/effort9/kyouka_taisaku.pdf (accessed October 22, 2024). [in Japanese].

Ministry of the Environment. Number of Hunting License Holders by Type. https://www.env.go.jp/nature/choju/docs/docs4/syubetu.pdf (accessed December 16, 2023). [in Japanese].

Mitani, N., Kumazawa, O. 2018. Hunter attitude towards recruitment of hunters in Kanagawa prefecture. Wildlife and Human Society. 6(1): 31-37. [in Japanese].

Ryan, E. L., Shaw, B. 2011. Improving Hunter Recruitment and Retention. Hum. Dimen. Wildl. 16(5): 311-317. DOI: 10.1080/10871209.2011.559530

Steeve D. Côté, Thomas P. Rooney, Jean-Pierre Tremblay, Christian Dussault, Donald M. Waller. 2004. Ecological Impacts of Deer Overabundance. Annual Review of Ecology, Evolution, and Systematics. 35. https://doi.org/10.1146/annurev.ecolsys.35.021103.105725

Suzuki, K., Kuwano, Y., Kanamori, Y., Kawauchi, Y., Uchimura, Y., Yasuda, M., Kondoh, H., Oka, T. 2022. A 25-year study of the population dynamics of a harvested population of sika deer on Kyushu Island, Japan. Forests. 13(5). https://doi.org/10.3390/f13050760.

Takeyama, E., Kuki, Y., Higashiguchi, A. 2017. Present situation of local hunters and issues to develop and secure them: By questionnaire survey to hunters in 4 towns in Wakayama Prefecture. Journal of Rural Planning Association. 36(2): 193-202. [in Japanese].

Tsunoda, H., Ueda, G. 2016. Status and attitudes of new hunters in Gifu Prefecture. Wildlife and Human Society. 4(1): 23-29. [in Japanese].

Yasuda, M. 2024. Sika deer in Kumamoto Prefecture. Kumamoto Wildlife Society. 12: 105-115. [in Japanese].

# UAV-Based Temporal Change Detections in an Open-pit Mine Using Python

**Hakan Durgun*, Arif Ögke, H. Oğuz Çoban**

Isparta University of Applied Sciences, Department of Forest Engineering, Isparta, Türkiye
*hakandurgun@isparta.edu.tr

**Abstract**
The practice of open-pit mining significantly contributes to the disruption of natural landscapes, pollution of the environment, and irreversible deformations, particularly deforestation. This cost-effective mining method conflicts with approaches to forest and nature conservation. Consequently, environmental groups and nature advocates have called for the restriction of open-pit mining operations and stricter regulation of mining permits. The aim of this study is to calculate temporal changes in an open pit mine using UAV photogrammetry data processed with Python. The study area is located within the borders of Burdur province in Southwestern Türkiye. This region has numerous new mining permit areas and many active open-pit mines. Python software was used to process point cloud and digital terrain model data produced by two different times UAV flights to ascertain the topographic changes. In recent years, the number of permits granted for open-pit mining activities in forest areas in Türkiye has increased significantly. Furthermore, the expansion demands of mines continue to pose a significant threat to natural ecosystems. The General Directorate of Forestry places great importance on determining whether mining operations comply with the permit areas and monitoring temporal changes within these permitted areas. According to the findings of this study, suggestions have been put forward regarding the essential software and hardware infrastructure required to implement an automated mining monitoring system.

***Keywords:*** *UAV, python, digital terrain model, open-cast mining, change detection*

## 1. Introduction

Türkiye is situated on the Alpine-Himalayan mountain region, making it an extremely marble-rich nation (Soykan and Mutluer, 1996). Nonetheless, one of the main land use practices that upset the natural equilibrium, contaminate the environment, and have a detrimental impact on the existence of living things is mining. In general, open pit mining operations result in more environmental degradation than other types of mining (Kocadağıstan, 1997; Acar, 2007). Because of this, permits for marble quarries should be granted only after careful examination, with the best sites chosen and their economic viability assessed, environmental effects taken into account, and comprehensive planning created (MTÇ, 2013). The appropriate forest administrations check mines operating in forest areas in accordance with Article 16 of the Forestry Law No. 6831 to make sure the miners are carrying out their operations in compliance with the permits issued. The teams measure the operating license area and the disposal areas where the mine's waste is discharged during these inspections, and they also check for permission area infractions.

The use of remote sensing and Unmanned Aerial Vehicles (UAV) technologies to control open pit mines has serious advantages. The practice of identifying and logging electromagnetic energy reflected from objects using sensor is known as remote sensing. Yomralıoğlu (2000) states that after these data are processed to provide the needed information, provided to the last user. A tool that can assist the practitioner in planning and decision-making is the Geographic Information System (GIS). Remote sensing is a very powerful data source since the data may be utilized as a base in GIS (Balcı et al., 2000; Çoban, 2016). Unmanned aerial vehicles are a recent device to the aerial vehicles utilized as platforms for remote sensing. Because of their practical use and reduced cost as compared to other aerial platforms, UAVs provide quick and appropriate answers to problems that arise (Durgun et al., 2022). The data gathered from UAVs can be utilized in forestry research for monitoring, management, and decision-making processes (Durgun et al., 2023). Furthermore, it is well recognized that when used by artificial intelligence (AI) techniques, UAV data can become an even more potent and important source of information (Liu et al., 2021). Numerous forestry applications have had success with AI techniques (Lefsky et al., 1999; Tsuya et al., 2021, Moghaddam et al., 2002). It is acknowledged that using AI technologies can help with a variety of engineering issues (Aylak et al., 2021; Durgun et al., 2023).

The purpose of this paper is to use Python software, remote sensing and GIS techniques to monitor and identify changes in an open pit mine. The goal is to create a workable approach that forest administrations can apply to their audits and assessments in this way. One of the open pit mines inside the administrative borders of the Isparta Regional Directorate of Forestry served as the study area. Data were gathered from the mine in the research area using the UAV on two separate occasions. To ascertain the alterations in the mine, photogrammetric techniques were employed to examine these data, which were collected at intervals of seven months. These modifications were charted, areas that had changed and those that had not were determined, and volume calculations were done.

## 2. Materials and Methods

### 2.1. Material

Türkiye has 27 regional directorates for forests, one of which is the Isparta Regional Directorate of Forestry (IRDF). IRDF region, which includes the cities of Isparta, Burdur, and partly Afyon, is situated in the southwest of Türkiye (Figure 1). The total surface area of the mines inside the boundaries of IRDF is 8127.3 hectares, as per the 2021 Forest Management Plan (Figure 2). IRDF (2021) reports that out of these, 426 areas had a surface area more than 5 hectares, for a total size of 6292.18 hectares. The primary factor in choosing the study area was the mine's continuous activity, because some of them are dormant and abandoned.

Figure 1. Isparta Regional Directorate of Forestry (IRDF, 2021)

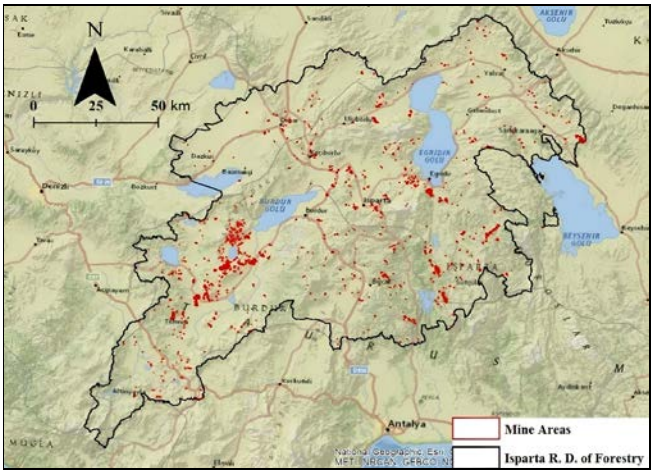


Figure 2. Distribution of mines in IRDF (IRDF, 2021)

The research area was chosen to be a marble quarry that was 8 km from Yarışlı Lake, Burdur and 32 km from the city centre of Burdur. Mining operations are still underway in the area's centre, and area of marble waste is visible in the northwest. Mining activities in the studied area began in 2012–2013 and became more intense, particularly after 2019, according to an analysis of past satellite photographs (Figure 3).

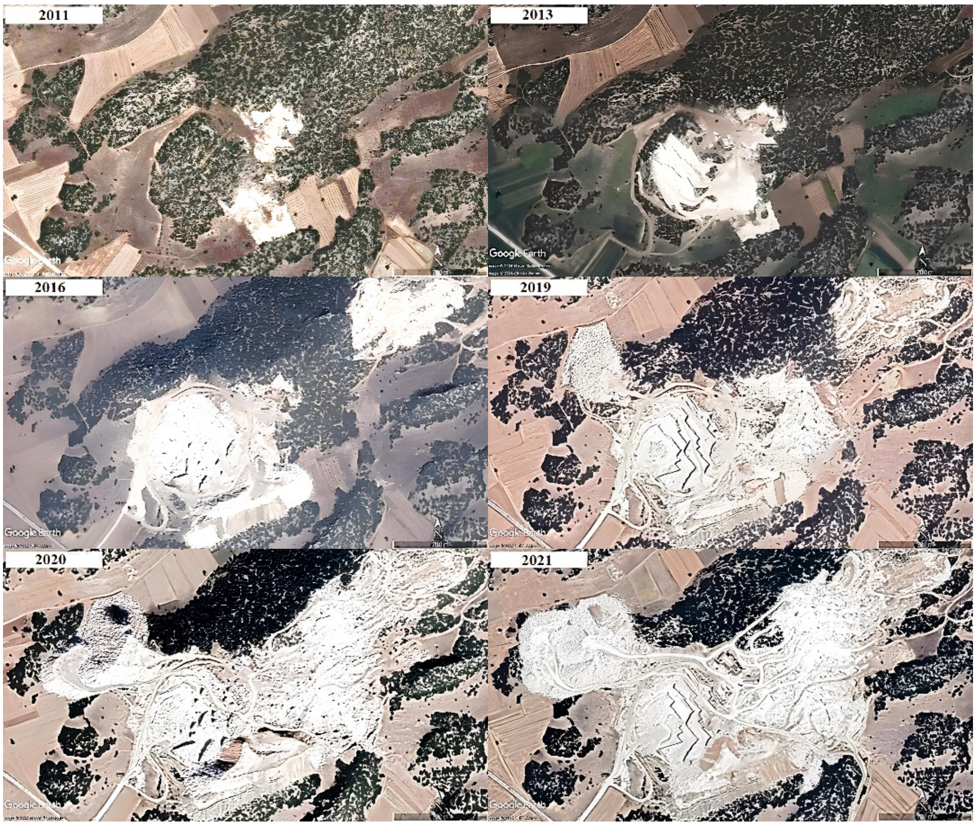


Figure 3. Temporal changes of the study area on satellite images (Google Earth, 2024)

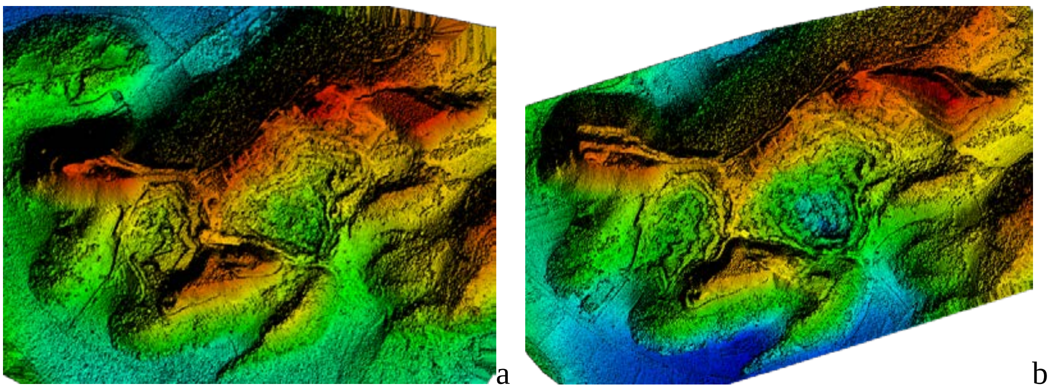
Field investigations were started as soon as the study area was determined. UAVs were used to gather data from the chosen area. Seven months later, the same region saw another round of data collection, from which the second data set for the change analysis was gathered. DJI Phantom 4 Pro UAV was employed for the first flight within the study's scope, and DJI Mavic

2 Pro UAV was used for the second flight (Figure 4). Pix4dcapture software, a free smartphone application, was utilized in the field research to guarantee that the UAV flew automatically in compliance with the photogrammetric acquisition settings. The aerial photos taken by the UAV were processed using the photogrammetry program Pix4dmapper (Pix4d, 2024). For all image acquisitions throughout both flights, the same overlap rate (80%), flying speed (5 m/s), and camera angle (90°) were applied. The results were reported, and descriptive statistics were produced using the Microsoft 365 (Microsoft, 2024). Volume calculations and spatial analysis were performed using the Anaconda Navigator (Spyder) application and the Python programming language (Anaconda, 2024; Python, 2024). The other maps in the study were created using ArcGIS (ArcGIS, 2024).

Figure 4. DJI Mavic 2 Pro and DJI Phantom 4 Pro UAV (Monti, 2018)

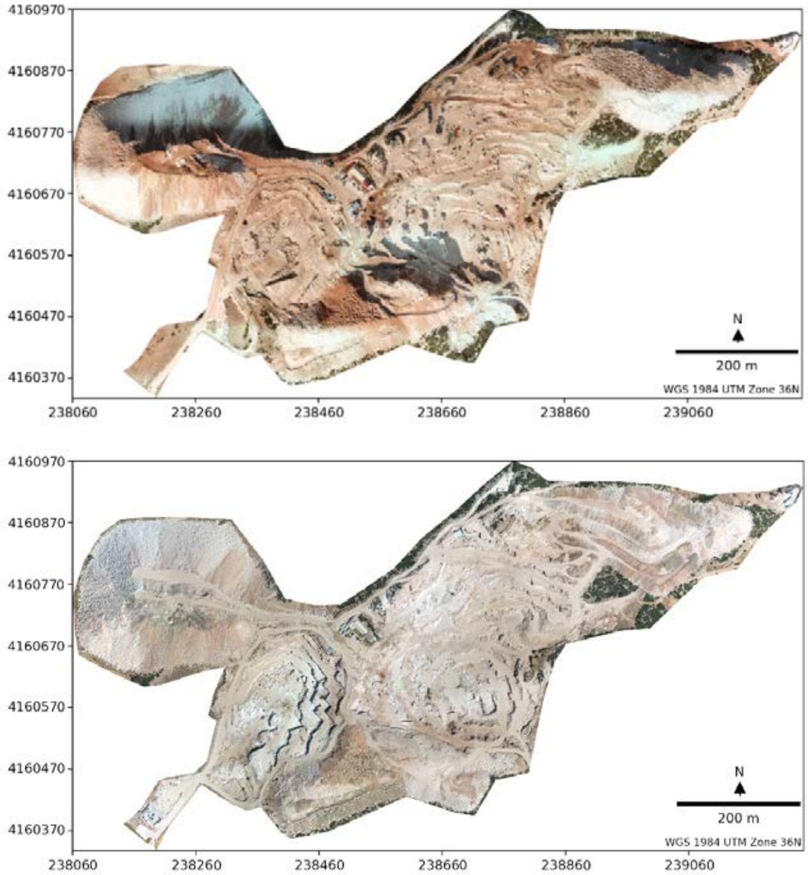
**2.2. Method**

Data such as digital terrain model (DTM), orthomosaic, and densified point cloud were produced as a result of processing the UAV photos collected during the field research (Figure 5; Figure 6). Photogrammetric data with a ground sampling distance of roughly 6.4 cm/pixel were obtained from both flights. To ensure that all the data had the same frame, these were clipped using Python in accordance with the research area border that was drawn in the GIS program. After that, the clipped data were adjusted using Python to a ground sampling distance of 10 cm/pixel. Following data processing, maps were made to show the amount and size of land changes by analyzing elevation, slope, and aspect. Python may be used to process, analyze, and produce maps using a variety of packages (Rey et al., 2023). In this study, UAV data were clipped and slope and aspect analysis were made using the GDAL (Geospatial Data Abstraction Framework) library. Temporal difference maps and elevation class maps were produced using the Numpy, Rasterio, Matplotlib and Geopandas libraries. The study's final stage involved volume computations. Volume calculations are very important, particularly for research done in places with structures like mines.



a b

Figure 5. DTMs of the study area; a) first flight, b) second flight



a
b

Figure 6. Orthomosaics of the study area; a) first flight, b) second flight

Changes in the region can therefore be quantitatively measured. A 1/25000 scale topographic map's corresponding elevation curves were digitized and used to verify the accuracy of the DTMs produced by the UAV. The topography change in the study area could be identified because the aerial photos used to create the topographic map were obtained prior to the mining operations. From the digitalized co-elevation curves in the GIS application, a DTM was created using Python. This DTM was then clipped in accordance with the study area's boundaries and set to a 10 cm ground sampling distance to be consistent with other data. The accuracy of the UAV data was verified, and the findings' compatibility was assessed, by comparing the DTM generated with the DTM acquired from the UAV.

## 3. Results

The elevation class maps were made from the DTMs of the study area (Figure 7) and Table 2 displays the areal distributions of the elevation classes. Upon closer inspection of Figure 7, it is evident that the mining operations have resulted in notable alterations to the terrain, with extensive excavations conducted, particularly within specific elevation ranges. Furthermore, it is acknowledged that higher elevation areas have constricted while lower elevation areas have increased. The region in the "<960 m" elevation class total area was increased, as Table 2 demonstrates. This increase suggests that the lower elevation areas of the mine were expanded while the excavation efforts were focused on this elevation band. The "960-980 m" and "980-1000 m" categories also showed a comparable increase, and it was seen that excavation work had been done in these elevation areas. In contrast, a decrease in area was noted in the elevation classes of ">1020 m" and "1000-1020 m."

**a**

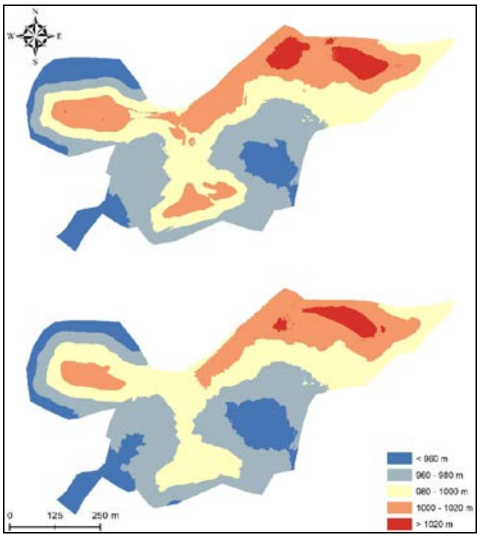



Figure 7. Elevation classes of the study area a) first flight, b) second flight

Table 2. Temporal changes at the elevation classes

| Elevation classes (m) | Area (ha) | |
|---|---|---|
| | First flight | Second flight |
| <960 | 4.7 | 5.6 |
| 960-980 | 10.8 | 11.7 |
| 980-1000 | 10.7 | 11.8 |
| 1000-1020 | 8.8 | 6.6 |
| >1020 | 1.6 | 0.9 |

**b**

Figure 8 displays the slope class maps made using DTMs generated for the study area, and Table 3 includes the area-wide distribution of slope classes. Based on the analysis of these data, it is believed that the expansion of the production area and the rise in production are connected to the area increase in low slope classes. Changes in slope classes show that the quarry's topography has undergone significant reshaping, while decreases in steep and sloping sections indicate the severity of excavation operations in certain areas.

**a**

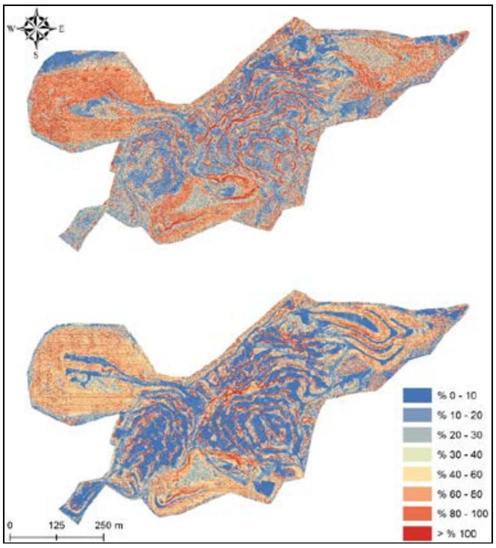



Figure 8. Slope classes of the study area a) first flight, b) second flight



**b**

Table 3. Temporal changes at the slope classes

| Slope classes (%) | Area (ha) | |
|---|---|---|
| | First flight | Second flight |
| 0 - 10 | 5.1 | 9.2 |
| 10 - 20 | 6.2 | 5.4 |
| 20 - 30 | 4.4 | 3.3 |
| 30 - 40 | 3.3 | 2.6 |
| 40 - 60 | 5.3 | 6.4 |
| 60 - 80 | 4.6 | 4.9 |
| 80 - 100 | 3.0 | 2.0 |
| > 100 | 4.8 | 2.8 |

Figure 9 displays the aspect class maps made using the DTMs generated for the research area, and Table 4 includes the aspect classes' areal distribution. While the increase in the south and west facing areas shows that the areas in these directions have increased or new excavation grounds have been opened, the decrease in the north and east facing areas suggests that some of the slopes in these directions have vanished or changed. These shifts in aspect classes offer crucial hints concerning the ways in which mining operations modify the topography in terms of direction and slope.

a

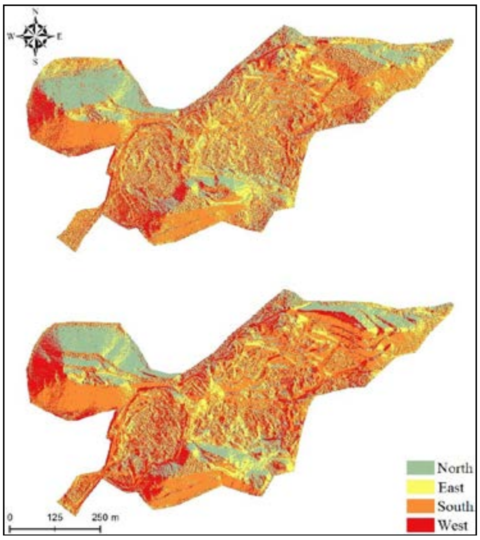



Figure 9. Aspect classes of the study area a) first flight, b) second flight

Table 4. Temporal changes at the aspect classes

| Aspect classes | Area (ha) | |
|---|---|---|
| | First flight | Second flight |
| North | 9.8 | 9.2 |
| East | 7.7 | 6.4 |
| South | 11.5 | 12.1 |
| West | 7.6 | 8.8 |

b

Using the Python programming language, the DTMs made for the research area were extracted from one another, yielding change maps. Volume calculations were carried out in Excel using the attribute tables of the change maps. The area units were translated into $m^2$ in the computations by accounting for the fact that each pixel has an area of 0.01 $m^2$ due to its 10x10 cm size. The elevation discrepancies, which are expressed in meters, were multiplied by these areas, and the volume equivalent of each difference value was computed in cubic meters ($m^3$). Figure 10 displays the map illustrating the research area's seven-month change.

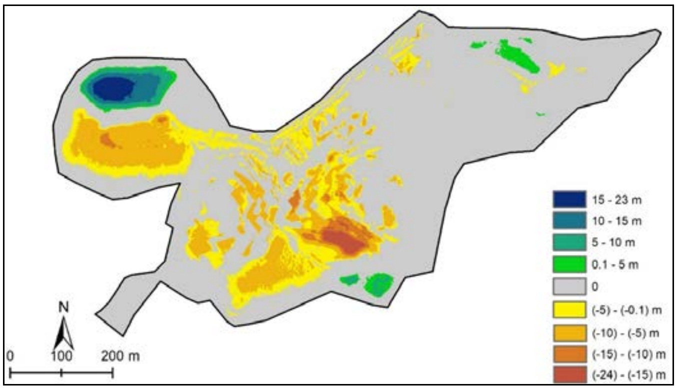


Figure 10. Seven-month changes in the study area (January 2023 - August 2023)

Upon closer inspection, Figure 10 reveals that over the 7-month period, marble extraction activities were conducted in the center of the research area, while the marble waste was piled in the northeast and southeast regions, particularly in the northwest. The orthomosaic and point clouds indicate that, despite the observation of excavation in the vicinity northwest of the study area, no marble extraction operations took place there; instead, the region used as an area of marble waste. It is believed that the excavation in this location is being done to lessen the elevation difference by increasing the dumping area's surface area and so saving fuel for the dumping vehicles. The results show that throughout the seven months, in the research area, a total volume of 601 589.01 $m^3$ of excavation and 192 858.88 $m^3$ of filling were calculated.

Figure 11 shows the change map between the DTM data for the study area produced using topographic map and the DTM created from the UAV (generated by the second flight). The changes since the mine's founding are depicted in Figure 11. It is noted that Figure 10 and Figure 11's outcomes are comparable. Excavations occur in the central region of the quarry because it is evident that this is where the majority of the marble extraction activity occurs. The research area's northeast and south regions, particularly in the northwest, used as area of marble waste. Based on the findings, from the first day until the last UAV flight, a total of 2 807 086.21 $m^3$ of excavation and 2 086 266.08 $m^3$ of filling volume were calculated.

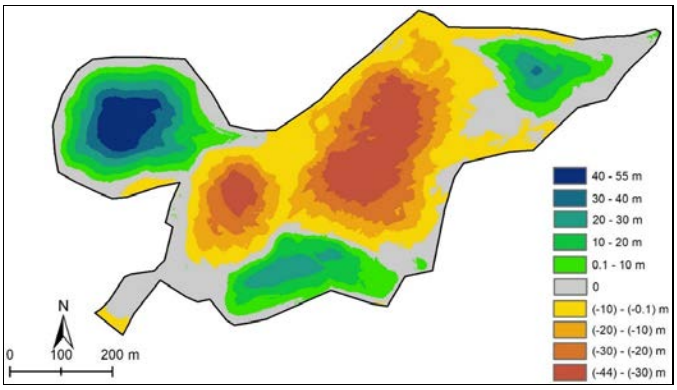


Figure 11. Temporal changes in the study area (2011 - August 2023)

The study's conclusions show that using Python and UAV together allows for efficient mapping of the study area's changes and volume calculations. Upon examining the change maps (Figures 10 and 11) that were generated, it is evident that the outcomes align with the satellite photos (Figure 3), orthomosaics created (Figure 6), and field observations. In order to improve the monitoring and assessment of changes in the study areas, certain recommendations have been made for more precise volume calculations in subsequent research.

1. To allow for more thorough monitoring of temporal changes, photographs can be taken in the research area at shorter intervals.
2. The accuracy of UAV data can be improved by establishing a sufficient number of ground control points evenly distributed over the survey area.
3. Change area and volume calculations obtained by the UAV can be verified by taking physical measurements in the research area. As a result, it is possible to improve precision and accuracy in image interpretation and data processing.

## 4. Discussion and Conclusion

In this paper, GIS techniques, Python, and UAV-based remote sensing were used to thoroughly examine the topographic changes that occurred in a mining hole over a seven-month period. The findings demonstrate that the area's topography has undergone substantial alterations as a result of the mine's operations. Extensive excavation activities were conducted, particularly in the study area's center and in specific elevation ranges. This resulted in a fall in elevation in certain areas and filling operations in other areas. The entire quantity of topographic change in the research area was calculated, and the environmental effects of marble extraction operations were assessed by calculating the quantities of excavation and filling. It was found that where excavation was concentrated, the topographic structure was significantly changed, and filling worked well in regions where waste of marble was accumulated. These findings offer crucial information for a deeper comprehension of how mining operations and modifications to land use affect the environment.

The results, which are consistent with previous research, demonstrate that topographic changes in the study area may be accurately identified and measured through the use of Python software and UAV-based remote sensing (Türk et al., 2022). It is recognized that utilizing the vector management plan data from various time periods in GIS, one can ascertain changes in forest regions (Çoban and Gündoğdu, 2020). However, surface models are required for volume computations, just as in this work. Despite being extensively employed in topographic investigations, surface models obtained from satellite data are not precise enough for volume calculations (Çoban and Eker, 2009; Durgun and Çoban, 2023). For instance, UAV models included in this study have a ground sampling distance of 10 cm and are consequently more accurate than SRTM data, which offer 30x30 m resolution (Durgun et al., 2022).

According to research comparing UAV-based volume calculations with field measurements in open pit mines, UAV photogrammetry has a success rate of more than 95% (Yiğit et al., 2023). It is known that the volume calculated with the UAV showed a difference of 1.3% in a study where the excavation and filling volumes calculated with GNSS (Global Navigation Satellite System) measurements in an open pit mine were taken as reference. This is in accordance with the reliable limit of ±3% (Mazhdrakov, 2007; Kabadayı, 2022). The outcomes align with both field observations and satellite data, and the use of UAV photogrammetry proved effective in charting the open-pit mine's alterations. UAV photogrammetry was also used to calculate volumes, and while the results are generally consistent, it is advised to take the aforementioned suggestions into account for more precise results.

**Acknowledgements**

We express our gratitude to TUBITAK (the Scientific and Technical Research Council of Türkiye) for providing funding for this research under project number 2209A.

**References**

Acar, D.Ö. 2007. Türkiye'de açık ocak kömür madenciliği sonrası peyzaj onarım çalışmalarinin irdelenmesi. (Ankara Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi)

Anaconda, 2024. Anaconda online. https://www.anaconda.com/ (Last date of access: 04.08.2024)

ArcGIS, 2024. ArcGIS online. https://www.arcgis.com/index.html (Last date of access: 04.08.2024)

Aylak, B.L., İnce, M., Oral, O., Süer, G., Almasarwah, N., Singh, M., Salah, B. 2021. Application of machine learning methods for pallet loading problem. Applied Sciences. 11(18): 8304.

Balcı, İ., Çoban, H.O., Eker, M. 2000. Coğrafi bilgi sistemi. SDÜ Orman Fakültesi Dergisi. 1(A): 115-132.

Çoban, H.O. 2016. Türkiye'nin yer gözlem uydu sistemleri ve ormancılık uygulamalarında kullanılabilirliği. Türkiye Ormancılık Dergisi. 17(1): 99-107.

Çoban, H. O., Eker, M. 2009. SRTM verileri ile bazı topoğrafik analizler: Isparta Orman Bölge Müdürlüğü örneği. SDU Orman Fakültesi Dergisi. A(2): 76-91.

Çoban, H.O., Gündoğdu, Ş. 2020. Orman alanlarındaki değişimlerin CBS tabanlı belirlenmesi: Çamsu Orman İşletme Şefliği örneği. Turkish Journal of Forestry. 21(1): 60-69.

Durgun, H., Çoban, H.O. 2023. Tarım, orman ve su bilimlerinde öncü ve çağdaş çalışmalar: Isparta ve Burdur bölgesindeki orman ekosistemleri ve topoğrafik değişkenler arasindaki ilişkilerin değerlendirilmesi. Duvar Yayınları, 113-137.

Durgun, H. Çoban, H.O., Eker, M. 2022. İnsansız hava aracıyla elde edilen hava fotoğraflarından kızılçam ağaçlarının çap ve boylarının ölçümü ve gövde hacminin tahmini. Turkish Journal of Forestry. 23(4): 255-267.

Durgun, H., İnce, E.Y., İnce, M., Çoban, H.O., Eker, M. 2023. Evaluation of tree diameter and height measurements in UAV data by integrating remote sensing and machine learning methods. Gazi Mühendislik Bilimleri Dergisi. 9(4): 113-125.

Google Earth, 2024. Google Earth Online. https://earth.google.com/web (Last date of access: 10.07.2024)

IRDF, 2021. Isparta Regional Directorate of Forestry Management Plan Data.

Kabadayı, A. 2022. Maden sahasının insansız hava aracı yardımıyla fotogrametrik yöntemle haritalanması. Türkiye İnsansız Hava Araçları Dergisi. 4(1): 19-23.

Kocadağıstan, M.E. 1997. Pasinler-Esendere kum ocakları doğa onarımı ve rekreasyonel alan kullanımı planlaması. (Yüksek lisans tezi, Atatürk Üniversitesi)

Lefsky, M.A., Cohen, W.B., Hudak, A., Acker, S.A., Ohmann, J.L. 1999. Integration of lidar, Landsat ETM+ and forest inventory data for regional forest mapping. International Archives of Photogrammetry and Remote Sensing. 32(3/W14): 119-126.

Liu, T., Sun, Y., Wang, C., Zhang, Y., Qiu, Z., Gong, W., Duan, X. 2021. Unmanned aerial vehicle and artificial intelligence revolutionizing efficient and precision sustainable forest management. Journal of Cleaner Production. 311: 127546.

Mazhrakov, M. 2007. Mine Engineering. Sofia: Sofia Univerisity.

Microsoft, 2024. Microsoft Online. https://www.microsoft.com/tr-tr/microsoft-365/ (Last date of access: 08.04.2024)

Moghaddam, M., Dungan, J. L., Acker, S. 2002. Forest variable estimation from fusion of SAR and multispectral optical data. IEEE Transactions on Geoscience and Remote Sensing. 40(10): 2176-2187.
Monti, C. 2018. Mavic 2 Pro vs. Phantom 4 Pro Online. https://dronedj.com/2018/11/25/mavic-2-pro-vs-phantom-4-pro/ (Last date of access: 01.08.2024)
MTÇ, 2013. Mermer ve Taş Ocaklarının Rehabilitasyonu Çalıştayı Sonuç Bildirgesi. Süleyman Demirel Üniversitesi, 17-18 Haziran- 2013, Isparta.
Pix4d, 2024. Pix4d online. https://www.pix4d.com/ (Last date of access: 01.08.2024)
Python, 2024. Python online. https://www.python.org/ (Last date of access: 08.08.2024)
Rey, S., Arribas-Bel, D., Wolf, L.J. 2023. Geographic data science with python. Chapman and Hall/CRC.
Soykan, F. Mutluer, M. 1996. Türkiye'de madencilik ve maden yataklarının coğrafi dağılışı. Ege Ü. Edebiyat Fak. Ege Coğrafya Dergisi. 8: 37-57.
Tsuya, K., Fujii, N., Kokuryo, D., Kaihara, T., Sunami, Y., Izuno, R., Mano, M. 2021. A Study on tree species discrimination using machine learning in forestry. Procedia CIRP. 99: 703-706.
Türk, Y., Canyurt, H., Eker, R., Aydın, A. 2022. İnsansız hava aracı ile orman yolu kazı ve dolgu hacimlerinin belirlenmesi: Bolu-Taşlıyayla örneği. Ormancılık Araştırma Dergisi. 9: 97-104.
Yiğit, A.Y., Kaya, Y., Şenol, H.İ. 2023. Açık maden ocaklarında insansız hava aracı (İHA) kullanımı. Mühendislik Bilimleri ve Tasarım Dergisi. 11(1): 225-235.
Yomralıoğlu, T. 2000. Coğrafi Bilgi Sistemleri: Temel Kavramlar ve Uygulamalar. Seçil Ofset Basımevi.

# Comparing Manual and Numerical Methods for Forest Road Design

**Hakan Durgun*, Serhat Oğuz Şergi, Mehmet Eker**

Isparta University of Applied Sciences, Department of Forest Engineering, Isparta, Türkiye
*hakandurgun@isparta.edu.tr

**Abstract**
Forest roads are linear infrastructure projects that must be affordable, practical, safe, and aesthetically pleasing. Precise fine-scale spatial analysis between the start and finish locations of the road segment is necessary for project design during the planning, design, application, and construction phases of road construction. The route is created in accordance with the goals and limitations of the forest road on a two-dimensional topographic map, in accordance with the traditional methods now in use in forest road design. Projects can be drawn autonomously or semi-autonomously using computer-aided design techniques, also referred to as modern approaches. Computer-aided methods are more successful than the classical method, according to existing practices and literature. The extent to which the computer-aided methods differs from the classical method as well as the points at which these differences become apparent during the project design process, have become a research subject. This study aims to identify these discrepancies and conduct a thorough analysis and evaluation from multiple angles. As a result, 35 distinct forest road segment projects that had previously been created by classical method were redesigned by computer-aided method setting for the same start and finish locations, and statistical tests were used to assess and interpret the outcomes. The outcomes demonstrate that, as predicted, the computer-aided design of forest roads produces accurate and timely results.

***Keywords:*** *Design of forest roads, route by road, volumetric excavation and filling, cost estimation and management, computer-aided design*

## 5. INTRODUCTION

For the purpose of using, protecting, and developing forests, forest roads allow the movement of people, supplies, and equipment as well as the removal of forest products. These roads vary from conventional highways in that they have a notable effect on the ecosystem (Eker and Ada, 2011). Türkiye has more than 250 thousand kilometers of roads inside forests overall (Eker, 2020). Designing forest roads is a challenging engineering issue that satisfies social, environmental, and economic demands (Öztürk, 2009). From an economic and environmental standpoint, it is imperative that all roads in this process be planned and designed before they are constructed (Ryan et al., 2004). These days, a variety of computer softwares are used to undertake cost evaluations in this planning (Musa and Mohammed, 2002; Aruga, 2005). It is acknowledged, that the road construction hierarchy (planning, design, programming, application and construction) is not consistently enough adhered to (Erdaş, 1997). Application and design are typically completed concurrently for pragmatic reasons. When forest roads are designed using the right methods, either by hand or computer-aided, the effects on the environment and economy are kept to a minimum and the right paths are identified.

The technical and financial viability of these processes determines the best approach for designing forest roads, which requires multiple stages of work. These stages include the identification and marking of positive cardinal points on a large-scale map, route straightening, horizontal curve placement, determining the axis of the road, obtaining the longitudinal and transverse profiles, cubage table, material profile, material distribution table and reporting procedures after the discovery summary has been prepared (Erdaş, 1997). While creating routes by hand (using maps that have elevation curves, compasses, and rulers) is feasible, it takes a lot of time, and it can be challenging to determine if this is the best course of action (Eker and Ada, 2011). Geographic Information System (GIS) applications make it easier to choose the route that is both technically and financially feasible by enabling you to test different routes fast and view the results promptly. It is feasible to do additional tasks semi-automatically or autonomously after locating the start and finish points on digital maps (Acar and Karabacak, 2012; Melemez et al., 2015).

The Faculty of Forestry at Isparta University of Applied Sciences (ISUBU) was founded in 1992 as a division of Süleyman Demirel University (SDU) and joined ISUBU in 2018. The Department of Forest Engineering at the Faculty of Forestry welcomed its first students in 1995, and the department offers an bachelor course called "Forest Roads" (ISUBU, 2024). The course covers the planning, construction, and design of forest roads, providing students with both theoretical and practical understanding in these areas. Students are required to manually build road segment projects using 1/2000 scale maps with elevation curves as part of their term assignments. Every year, the students produce projects that are stored in the laboratory. Each project follows an own route. Both manual and computer-aided projects have been produced for the courses in recent years. Every stage of these initiatives is assessed based on predetermined standards (Erdaş, 1997). The manual projects created by the "Forest Roads" course students were digitalized using GIS for this study, and the amounts of excavation and filling between the projects were contrasted. The statistical analysis of the cubage tables of projects prepared under identical field settings assessed the distinctions between manual and numerical methods.

## 2. Material and Method

### 2.1. Material

35 forest road segment projects that were assigned as term papers by students from 2006 to 2018 as part of the "Forest Roads" course were chosen as the research's material (Figure 1). The 35 student projects that were chosen for usage in the study took into account the following criteria:

1. Successful (those who, using a 100-point scoring system, have scored at least 75 points)
2. The project needs to be unique—it can't be the same or comparable.
3. A finished project (every stage of design needs to be finished)
4. The project's maps will not be destroyed or distorted (to avoid scale issues while digitizing)

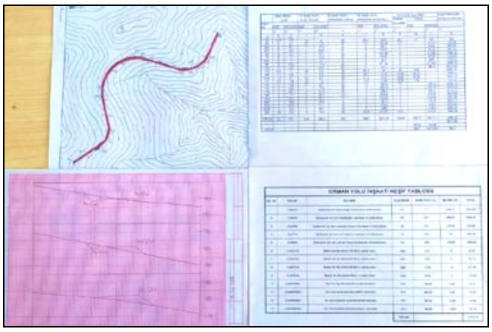


Figure 1. The student's forest road segment project example

The GIS tool NetCAD-GIS was utilized in this work to assist with the computer-aided design of forest road segments (NetCAD, 2024). The results were reported, spreadsheets were created, and descriptive statistics were produced using the Microsoft 365 program (Microsoft, 2024). The statistical tests in the study were implemented using the Python programming language and the Anaconda Navigator application (Anaconda, 2024; Python, 2024).

## 2.2. Method

Numbering and marking were applied to the 35 student projects that were chosen. The distances between these markers were measured using a precision ruler and The coordinate values for rectification were assigned based on the scale of the maps. Afterwards, the road axes in the projects (where maps with elevation curves were drawn on A4 size paper with all their elements) were transferred to the computer environment. Rectification was done beforehand in order to digitize the computerized road axes in the GIS environment. Prior to the projects being scanned, coordinate calculations and physically marked points were used in the rectification process (Figure 2). Following the process of rectification, the elevation curves inside the projects were vectorized and digital elevation models of the research regions were constructed (Figure 3). In the ensuing phases, these models proved useful for computing cubage.

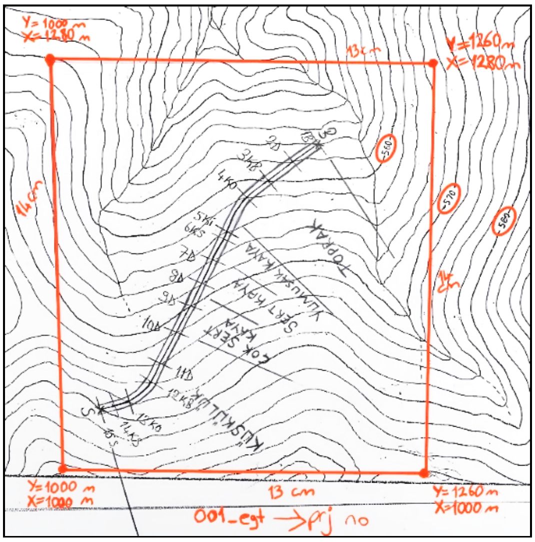



Figure 2. A student project example that has been scanned

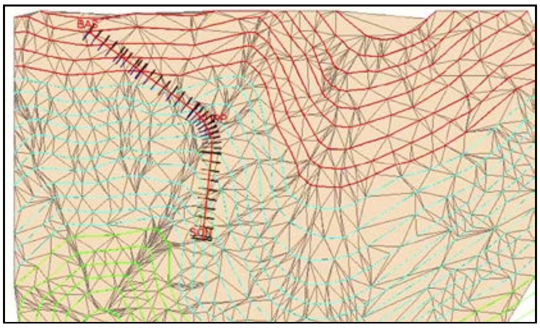


Figure 3: A sample of a forest road segment imported into a GIS environment

The road axes made during the manual project design phase were faithful and carried over to all of the projects that were converted to digital format. When designing forest road segments using a GIS system, the road axis is vectorized, bends are placed, establishing longitudinal profiles and land cross-sectional and the creation of the cubage table (Figure 4). For every project, each of these procedures has been meticulously carried out one at a time. In all projects, cross-sections were obtained at 10-meter intervals throughout the computer-aided design phase, and volume calculations were performed. In the last phase of the research, spreadsheets were also created using the cubage tables, which were based on the actual counting and calculations of the students. Consequently, two distinct cubage tables—one produced manually and the other by a computer-aided—were acquired for the identical road segment. The results of these two procedures were clearly proved by comparing the obtained (cubage table) data with statistical methods.

| Sıra | Kilometre | Kazı Alanı | Dolgu Alanı | S/K | Kazı Hacmi | Dolgu Hacmi | Brükner Değeri | Özel Aralık | Kazı Hacmi (H) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0+000.00 | 0.798 | 0.279 | 1.000 | 0.000 | 0.000 | 0.000 | | 0.000 |
| 1 | 0+010.00 | 0.580 | 0.418 | 1.000 | 6.891 | 3.483 | 3.408 | | 6.891 |
| 2 | 0+020.00 | 0.459 | 0.601 | 1.000 | 5.194 | 5.095 | 3.507 | | 5.194 |
| 3 | 0+030.00 | 0.343 | 0.031 | 1.000 | 4.010 | 7.161 | 0.356 | | 4.010 |
| 4 | 0+040.00 | 0.272 | 1.030 | 1.000 | 3.076 | 9.307 | -5.875 | | 3.076 |
| 5 | 0+044.00 | 0.266 | 1.110 | 1.000 | 1.078 | 4.280 | -9.077 | | 1.078 |
| 6 | 0+050.00 | 0.268 | 1.183 | 1.000 | 1.604 | 6.896 | -14.369 | | 1.604 |
| 7 | 0+060.00 | 0.284 | 1.138 | 1.000 | 2.759 | 11.631 | -23.241 | | 2.759 |
| 8 | 0+063.00 | 0.303 | 1.073 | 1.000 | 0.881 | 3.316 | -25.677 | | 0.881 |
| 9 | 0+069.00 | 0.348 | 0.945 | 1.000 | 1.953 | 6.056 | -29.780 | | 1.953 |
| 10 | 0+070.00 | 0.356 | 0.922 | 1.000 | 0.352 | 0.934 | -30.362 | | 0.352 |
| 11 | 0+080.00 | 1.044 | 0.139 | 1.000 | 6.998 | 5.304 | -28.667 | | 6.998 |
| 12 | 0+090.00 | 3.030 | 0.000 | 1.000 | 20.371 | 0.694 | -8.981 | | 20.371 |
| 13 | 0+100.00 | 5.256 | 0.000 | 1.000 | 41.429 | 0.000 | 32.438 | | 41.429 |
| 14 | 0+110.00 | 6.566 | 0.000 | 1.000 | 59.106 | 0.000 | 91.544 | | 59.106 |
| 15 | 0+120.00 | 6.456 | 0.000 | 1.000 | 65.110 | 0.000 | 156.654 | | 65.110 |
| 16 | 0+130.00 | 4.137 | 0.000 | 1.000 | 52.969 | 0.000 | 209.623 | | 52.969 |
| 17 | 0+138.87 | 0.528 | 0.300 | 1.000 | 20.694 | 1.331 | 228.986 | | 20.694 |
| 18 | 0+140.00 | 0.317 | 0.491 | 1.000 | 0.476 | 0.446 | 229.016 | | 0.476 |
| 19 | 0+145.00 | 0.019 | 1.447 | 1.000 | 0.841 | 4.847 | 225.010 | | 0.841 |
| 20 | 0+150.00 | 0.000 | 1.905 | 1.000 | 0.049 | 8.381 | 216.677 | | 0.049 |
| 21 | 0+155.00 | 0.000 | 2.083 | 1.000 | 0.000 | 9.984 | 206.693 | | 0.000 |
| 22 | 0+160.00 | 0.000 | 2.662 | 1.000 | 0.000 | 11.877 | 194.816 | | 0.000 |
| 23 | 0+165.00 | 0.000 | 3.415 | 1.000 | 0.000 | 15.192 | 179.625 | | 0.000 |
| 24 | 0+170.00 | 0.000 | 4.154 | 1.000 | 0.000 | 18.922 | 160.702 | | 0.000 |
| 25 | 0+175.00 | 0.000 | 3.686 | 1.000 | 0.000 | 19.599 | 141.103 | | 0.000 |
| 26 | 0+180.00 | 0.000 | 2.640 | 1.000 | 0.000 | 15.813 | 125.290 | | 0.000 |
| 27 | 0+185.00 | 0.000 | 1.922 | 1.000 | 0.000 | 11.403 | 113.887 | | 0.000 |
| 28 | 0+190.00 | 0.015 | 1.533 | 1.000 | 0.037 | 8.637 | 105.287 | | 0.037 |
| 29 | 0+190.49 | 0.017 | 1.501 | 1.000 | 0.008 | 0.737 | 104.558 | | 0.008 |
| 30 | 0+200.00 | 0.137 | 0.908 | 1.000 | 0.735 | 11.456 | 93.837 | | 0.735 |
| 31 | 0+210.00 | 0.427 | 0.464 | 1.000 | 2.818 | 6.856 | 89.799 | | 2.818 |
| 32 | 0+220.00 | 0.609 | 0.420 | 1.000 | 5.178 | 4.417 | 90.560 | | 5.178 |
| 33 | 0+230.00 | 0.782 | 0.254 | 1.000 | 6.953 | 3.368 | 94.145 | | 6.953 |
| 34 | 0+240.00 | 1.387 | 0.275 | 1.000 | 10.842 | 2.644 | 102.343 | | 10.842 |
| 35 | 0+250.00 | 2.417 | 0.076 | 1.000 | 19.020 | 1.757 | 119.606 | | 19.020 |
| 36 | 0+260.00 | 3.232 | 0.009 | 1.000 | 28.248 | 0.427 | 147.426 | | 28.248 |
| 37 | 0+270.00 | 2.200 | 0.474 | 1.000 | 27.160 | 2.418 | 172.169 | | 27.160 |
| 38 | 0+280.00 | 1.001 | 1.617 | 1.000 | 16.005 | 10.459 | 177.715 | | 16.005 |
| 39 | 0+283.08 | 0.774 | 1.844 | 1.000 | 2.731 | 5.327 | 175.119 | | 2.731 |

Figure 4. Cubage table generated within a GIS

**3. Results and Discussion**

35 forest road segments that were created using computer-aided and manual methods were examined in this study. To find potential scale and gross inaccuracies, the lengths of the road segments were initially compared. Table 1 displays descriptive statistics regarding the lengths of the road segments. The analysis of Table 1 reveals that the two methods' averages are quite similar. The measurements are consistent and the variances of the two data sets are similar, as indicated by the standard deviation numbers. The standard deviation figures demonstrate the consistency of the measurements and the similar variance of the two data sets. These findings demonstrate that the road length measurements for both approaches have a comparable distribution, and the measurement discrepancies are rather near. Even while the manual method predicts a slightly longer total road length than the computer-aided method does, this discrepancy does not significantly affect the evaluation as a whole. Moreover, a strong positive association between the project design approaches is indicated by the high correlation coefficient (0.98) between the two methodologies.

Table 2: Road segment length statistics for various approaches (n = 35)

| | Road Lengths (m) | |
|---|---|---|
| | Computer Aided Design | Manual Design |
| Mean | 372.10 | 374.11 |
| Standard Error | 18.13 | 18.10 |
| Standard Deviation | 107.28 | 107.08 |
| Sum | 13023.33 | 13094.00 |
| Correlation | 0.98 | |

The frequency and scatter plots of the lengths of the road segments created using the two different design procedures are displayed in Figure 5. These distributions were examined for normality using the Kolmogorov-Smirnov test. The computer-aided design method's p-value for the Kolmogorov-Smirnov test was 0.132, but the manual method's p-value was 0.369. According to these p-values, the two data sets are consistent with the normal distribution hypothesis. The results imply that the data are appropriate for the use of parametric tests and are in line with the descriptive statistics and graphs. The significance difference between the path lengths of the two techniques was assessed using the Independent Sample T-Test, and a p-value of 0.57 was discovered. This finding indicates that the difference achieved may have been random and that the mean difference between the two approaches is not statistically significant.

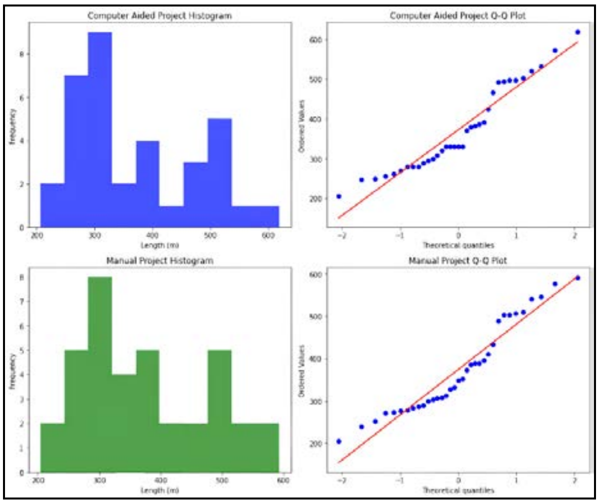


Figure 5. Distribution graphs of road length for design methods

Excavation volume data for both computer-aided and manual design approaches are summarized statistically in Table 2. The average excavation volume is not significantly different between the two ways; nevertheless, the average excavation volume is higher with the computer-aided design method than with the manual design method. Both methodologies' standard error and standard deviation numbers are comparable, suggesting that the outcomes are largely dependable and consistent. The computer-aided design method yields a substantially larger overall excavation volume than manual design in terms of volume. The high correlation coefficient (0.95) between the two approaches further suggests that the data are generally compatible and that the outputs of the computer-aided and manual design methods are parallel.

Table 2. Volumes of excavation for road segments using various methods (n = 35)

| | Excavation Volume ($m^3$) | |
|---|---|---|
| | Computer Aided Design | Manual Design |
| Mean | 1042.28 | 1003.30 |
| Standard Error | 146.13 | 141.08 |
| Standard Deviation | 864.52 | 834.66 |
| Sum | 36479.83 | 35115.45 |
| Correlation | 0.95 | |

The frequency and scatter plots of the excavation volumes of the road segments created using the two distinct methods are displayed in Figure 6. These distributions' normality was assessed using the Kolmogorov-Smirnov test. For the computer-aided design method, the p-value of the

Kolmogorov-Smirnov test was 0.008. The excavation volume data acquired using the computer-aided design method are not regularly distributed, as indicated by the low p-value. The p-value for the manual design method came out to be 0.098. Although the data do not precisely fit the normal distribution, this p-value suggests that the assumption of a normal distribution is met. This conclusion is further supported by the scatter plots shown in Figure 6. In conclusion, it is important to acknowledge that while the computer-aided design method's departure is more significant, the manual design method's divergence is also considerable. This makes using parametric tests less applicable and makes the use of non-parametric techniques in data analysis necessary. Therefore, to assess the significance difference between the excavation volumes of the two methods used, the non-parametric Wilcoxon Signed Rank Test was employed. The test produced a p-value of 0.002, which was computed. According to this p-value, there is statistically significant variation in the excavation volume between the two approaches. Consequently, it is stated that more research has to be done to determine how the methods differ from one another.

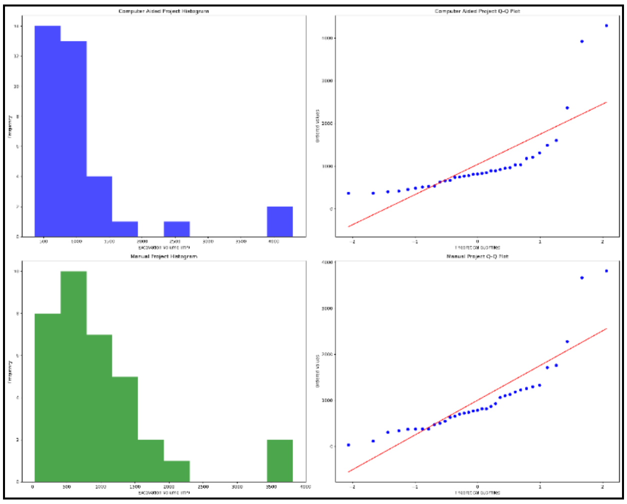


Figure 6. Distribution graphs of excavation volume for design methods

Summary statistics of the filling volume data for both the manual and computer-aided design approaches are shown in Table 3. The average filling volumes of the two approaches do not differ significantly. When compared to manual design, the average filling volume is smaller with the computer-aided design process. Both methods' standard error and standard deviation numbers are comparable, suggesting that the outcomes are largely dependable and consistent. The computer-aided design approach yields a smaller filling volume overall than the manual design method. Additionally, the data are generally consistent and the results of the computer-aided and manual design processes are similar, as indicated by the high correlation (0.95) between the two methods.

Table 3. Road segment filling volume statistics for various methods (n = 35)

| | Filling Volume ($m^3$) | |
|---|---|---|
| | Computer Aided Design | Manual Design |
| Mean | 551.55 | 569.75 |
| Standard Error | 97.86 | 103.19 |
| Standard Deviation | 578.94 | 610.50 |
| Sum | 19304.33 | 19941.25 |
| Correlation | 0.95 | |

Frequency and scatter graphs of the filling volumes of the road segments created using the two distinct methods are shown in Figure 7. The normality of these plots was evaluated using the Kolmogorov-Smirnov test. For the computer-aided design method, the p-value was 0.0024. The assumption of a normal distribution is invalid since this result shows that the filling volume data differs significantly from the normal distribution. Similarly, the data greatly diverged from the normal distribution, and the assumption of normal distribution is invalid, as indicated by the p-value for the test conducted using the manual design approach, which was 0.0097. These results are corroborated by the scatter plots in Figure 7. The application of parametric tests was affected by these findings, hence non-parametric approaches were chosen for data analysis. With the use of the Wilcoxon Signed Ranks Test, the p-value was found to be 0.053. It may be concluded that there is no statistically significant difference between the filling volumes of the two methods because the p-value is greater than 0.05. This does, however, suggest that minor adjustments can have a substantial impact and that the results are approaching the significance limit.

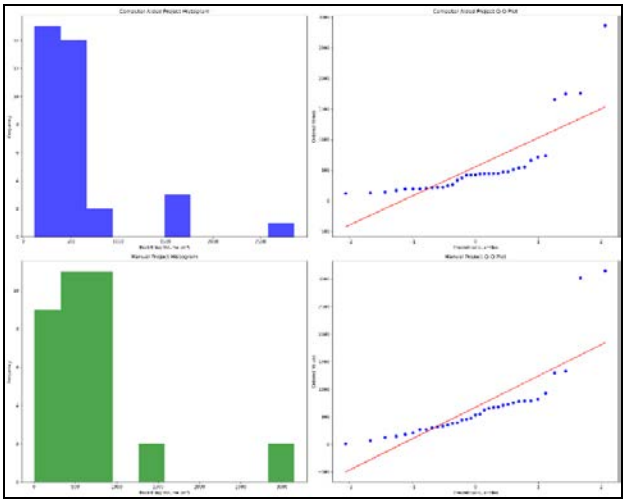


Figure 7. Distribution graphs of filling volume for design methods

The lengths, excavation volumes, and filling volumes of forest road segments studied using manual and computer-aided design methods were compared in this study, and the differences were statistically assessed. The assessments revealed no discernible difference between the two approaches in terms of the road segment lengths; that is, the outcomes produced by the manual and computer-aided methods were comparable. Nonetheless, the computer-aided design approach yielded noticeably better results in terms of excavation volumes, and this difference was shown to be statistically significant. The difference between the two approaches' results in filling volumes was determined to be nearly significant. Given that it yields more accurate results, these findings imply that the computer-aided design method might be more useful in sensitive investigations (Öztürk, 2009). Still, the outcomes of the manual approach are just as trustworthy. As a result, the best way to choose a method for a project is to consider its needs as well as the type of outcomes that are expected.

The study's findings highlight the various benefits and drawbacks of manual and computer-aided design methods. The results of this study demonstrate that digital tools and software can analyze complicated data more precisely and quickly, in line with the conclusions of earlier studies (Melemez et al., 2015; Türk, 2022). However, for small-scale projects, manual methods are thought to be more economical and require less technological infrastructure. It should be remembered, nevertheless, that the human aspect, as in this study, can affect the margin of error of manual approaches. Since the techniques for excavation and filling volume are likely to vary (Acar & Karabacak, 2012), it is believed that this variation was made more pronounced because the manual project designs were completed by students who were still learning how to do this work. As a result, the ideal strategy is to choose suitable methods based on the needs and project budgets. The methods to be utilized in projects should be carefully considered, taking into account the benefits and drawbacks of each.

## 4. Conclusion and Suggestions

A total of 35 projects were assessed in this study. It is advised to expand the sample size to enable the results to be more broadly applicable. An expanded dataset could potentially enhance the dependability of the results and offer a more lucid depiction of the variations amongst the techniques. Furthermore, every road segment that was created using the manual method was completed by the students. The students' mistake rate can be high since they are inexperienced with designing forest roads. It is advised that comparable research be carried out by specialists with greater expertise. By doing this, design flaws can be reduced and the accuracy of the final product can be raised. The study's conclusions demonstrate that there are variations in the volume computations between the design approaches. The causes of these variations, nevertheless, are not entirely known. Specifically, the question of whether variations in land slopes contribute to different methods has not been explored. Analyzing the impact of terrain slopes is a crucial area of inquiry for next investigations and can aid in understanding these variations.

A theoretical assessment of the design methods was done in this work. Real forest roads should be constructed using a variety of design methods for upcoming research, and the outcomes should be contrasted with real-world scenarios. This can assist in evaluating the practical applicability and accuracy of the theoretical conclusions. To better illustrate how the results align with field settings, testing the methods' accuracy and efficacy in actual applications is recommended. In this study, the computer-aided design method produced cross-sections at 10-meter intervals, but the manual method produced longer cross-section intervals. It is suggested that various section intervals be examined in comparable research because it is believed that this is also useful in differentiating the results.

## Acknowledgements

We express our gratitude to TUBITAK (the Scientific and Technical Research Council of Türkiye) for providing funding for this research under project number 2209A.

## References

Acar, H. H., Karabacak, M., 2012. Göller Bölgesi Orman Yolu Inşaatlarında Yaklaşık Maliyet Ve Hakediş Değerlerinin Irdelenmesi. SDÜ Orman Fakültesi Dergisi. 13: 21-27.

Anaconda, 2024. Anaconda online. https://www.anaconda.com/ (Access date: 08.08.2024)

Aruga, K., 2005. Tabu Search Optimization of Horizontal and Vertical Alignments of Forest Roads. Journal of Forestry Research. 10: 275-284.

Eker, M., Ada, N., 2011. Orman Yolu Kalite Analizine Yönelik Ölçüt Ve Gösterge Setinin Oluşturulması. Turkish Journal of Forestry. 12(2): 89-97.

Eker, M., 2020. Sürütme Yolları Ve Yoğunlukları Üzerine Değerlendirmeler. Turkish Journal of Forestry. 21(4): 396-406.

Erdaş, O., 1997. Orman Yolları. KTÜ Orman Fakültesi Yayın No: 187/25-188/26, Cilt I-II, Trabzon.

ISUBU, 2024. ISUBU online. https://orman.isparta.edu.tr/ (Access date: 08.04.2024)
Melemez, K., Ateşoğlu, A., Özkan, C., Tunay, M., 2015. Orman Yollarının Bilgisayar Destekli Tasarım Metodu Ile Projelendirilmesi. Bartın Orman Fakültesi Dergisi. 17(25): 29-41.
Microsoft (2024). Microsoft online. https://www.microsoft.com/tr-tr/microsoft-365/ (Access date: 08.04.2024)
Musa, M.K.A., Mohamed, A.N., 2002. Alignment and Locating Forest Road Network By Best-Path Modeling Method. Asian Journal of Geoinformatics, Forestry Section.
NetCAD (2024). NetCAD online. https://www.netcad.com/ (Access date: 08.08.2024)
Öztürk, T., 2009. Orman Yolu Planlarının Oluşturulmasında Netpro Yol Modülünün Kullanılması. Eskişehir Osmangazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi. 22(3).
Python (2024). Python online. https://www.python.org/ (Access date: 08.08.2024)
Ryan, T., Phillips, H., Ramsay, J., Dempsey, J., 2004. Forest Road Manual, Guidelines for the Design, Construction and Management of Forest Roads, COFORD, Natural Council for Research and Development, Dublin.
Türk, Y., 2022. Orman Yolu Büyük Onarımı Çalışmalarında Yaklaşık Maliyet ve Hakediş Değerlerinin İncelenmesi: Yığılca Orman İşletme Müdürlüğü Örneği. Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi. 18(2): 316-326.

# Estimating Sediment Yield from a Road Network by Using a GIS-Based Sediment Prediction Model

**Esin Erdoğan Yüksel[1*], Ömer Faruk Karan[1], Abdullah Emin Akay[1], Ebru Bilici[2,3]**

[1]Bursa Technical University, Faculty of Forestry, Department of Forest Engineering, Bursa, Türkiye
[2]University of Idaho Experimental Forest, College of Natural Resources, Moscow, USA.
[3]Giresun University, Dereli Vocational High School, Giresun/Türkiye
*esin.yuksel@btu.edu.tr

## Abstract

A significant part of the fresh water resources available on earth are provided by forest basins. Especially the upper parts of the basins provide quality and sustainable water production as well as services such as erosion and flood control, soil protection, landslide, avalanche and rockfall prevention. However, forestry activities are also carried out in these basins, and the execution of these activities can be efficient through planned roads in forest areas. Forest roads cause compaction on the soil surface, surface runoff formation, increase in stream peak flows and temperature, sediment transport, erosion and thus deterioration of water quality. In this study, the SEDMODL method, a GIS-based sediment prediction model, was used to calculate the sediment production from the road network in a sample study area. Gürgen Creek Watershed, which was chosen as the study area, is a sub-basin of the Doğancı Dam, located on the Bursa-Osmangazi borders in the Marmara Region and built on the Nilüfer Stream. The altitude above sea level in the watershed varies between 530 m and 1093 m. 80.51% of the total watershed area is forest, 13.27% is agricultural and 6.22% is pasture area. The results indicated that the sediment yield from road sections highly depends on several erosion factors. Even though their effects on sediment yield vary based on the road types (i.e. secondary or county-maintained roads), the most important attribute to consider in predicting sediment yield are road use, slope, and cut-slope heights.

***Keywords:*** *Erosion, sediment yield, forest road, GIS*

## 1. Introduction

A significant portion of the freshwater resources available in the world are provided by watersheds located within the forest lands. Especially the upper parts of the basins provide services such as erosion and flood control, soil protection, landslide, avalanche and rock fall prevention, as well as quality and sustainable water production. Forestry activities are carried out in these watersheds, and the execution of these activities can be more efficient through planned roads in forest lands. The planning of forest road activities should be performed by using appropriate methods and implemented in the field accordingly (Toscani et al., 2020). Forest roads are established to support sustainable forest management, ensure the regular supply of resources and to maintain the forest ecosystems (Kastridis, 2020).

Although forest roads occupy a small area within the amount of forest area, they significantly affect water flow paths and, as a result, have a significant impact on the change of flow production processes and finally on hydrological water events (Wemple et al., 2018). Inappropriate and unplanned forest roads and stream crossing points cause the road network to deteriorate (Kastridis and Stathis, 2020). It is necessary to provide the necessary information to better understand the flow and erosion processes on forest roads and reduce sediment production and transport to streams (Ramos-Scharrón et al., 2016). Different models have been developed recently regarding these changes in forest roads. Various models such as the Water Erosion Prediction Project (WEPP), Road Sediment Distribution Model (SEDMODL) and Washington Road Surface Erosion Model (WARSEM) have been developed to reveal the effects of forest road construction on hydrological processes, erosion and sediment yield (Surfleet et al., 2011).

The Sediment Distribution Model (SEDMODL), developed by Boise Cascade Corporation in 1999, is frequently used to estimate the sediment yield resulting from forest roads (Boise Cascade Corporation, 1999). SEDMODL is a GIS-based road erosion and distribution model that identifies road segments with high potential to transport sediment to streams (Damain, 2003). Akay et al. (2008) presented a combination of GIS and a sediment model (SEDMODL) to estimate the average annual sedimentation amount from road. This method is based on empirical relationships between erosion factors, including the type of road use, the parent material of the area used in road construction, road surface condition, longitudinal slope of the road, vegetation cover on the cut-slope and distance from the water bodies (Akay et al., 2008).

In a previous study, the sedimentation rate resulting from existing forest roads was estimated using SEDMODL and based on influential factors such as geology, road structure, slope, rainfall amount, vegetation cover and drainage network with the help of GIS by Asadollahi et al. (2016). In estimates made without using SEDMODL, the annual amount resulting from this road network was determined as 1576.4 tons. However, when SEDMODL was applied based on waterway distance, this amount was estimated to be 140.7 tons. The results revealed that the amount of sediment produced by roads constituted only 1.33% of the total sediment observed at the basin outlet, whereas roads covered only 0.017% of the basin area (Dalir et al., 2014).

Based on previously conducted studies, it is widely accepted that the hydrological response of watersheds will change as the hydrological characteristics of forest roads, morphological structure and land uses change. It is known that one of the biggest problems caused by road construction in forests and natural areas is the formation of large gullies around the roads and the formation of various landslides (Carl and Li, 2006). Therefore, investigating the impact of the road on the amount of sediment accumulation provides guidance in landslide management and intervention. Studies on this subject enable the identification of sensitive and risky areas and enable the development of the most appropriate methods to control erosion. In this study, the SEDMODL method, a GIS-based sediment prediction model, was used to calculate sediment production from the road network in a case study area.

## 2. Material and Methods

### 2.1. Study Area

Gürgen Creek Watershed, which was chosen as the study area, is a sub-basin of the Doğancı Dam, located in the city of Bursa and built on the Nilüfer Stream (Figure 1). The area of the watershed is 273 ha and the average annual rainfall is 1043 mm. The elevation in the watershed varies between 530 m and 1093 m. About 80.5% of the total area of the watershed is forest, 13.27% is agricultural land and 6.22% is pastureland. There are two types of roads including gravel roads and native surface forest roads in the study area (Table 1).

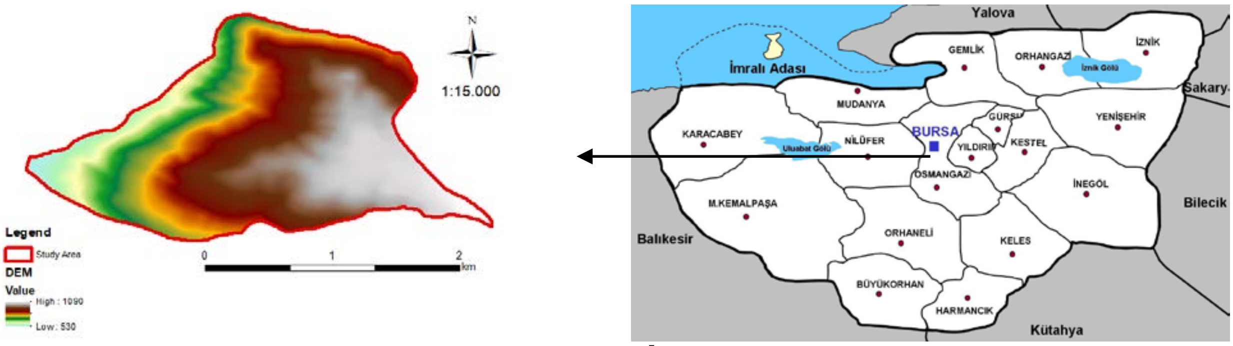



Figure 1. Study area

Table 1. Type and length of the roads in the study area

| Road Type | Length (m) |
|---|---|
| Gravel roads | 390 |
| Forest roads (native surface) | 4517 |

### 2.2. Sediment Prediction

For the SEDMODL method used in this study, the total sedimentation per year delivered from each road section, including road tread sediment and cut-slope sediment, was calculated according to Equation 1 (Boise Cascade Corporation, 1999).

$$Total\ Sediment\ (ton/year) = (T_S + C_S)A_f \quad (1)$$

In Equation 1, *Ts* is defined as the sedimentation caused by the road surface and roadside streams, *Cs* is defined as the sedimentation caused by cut-slope, and *Af* is defined as the factor related to the road age. The sedimentation caused by the road surface depends on the morphometric characteristics of the road (width, length and road grade), road type, geological structure of the region and rainfall amount. Based on these factors, the erosion amount rate is calculated according to Equation 2.

$$TS = L_r W_r GE_r S_f T_f G_f P_f D_f \quad (2)$$

The parameters in Equation 2 are road length (*Lr*), road width (*Wr*), geological erosion rate (*GEr*), road surface material (*Sf*), road traffic (*Tf*), road grade (*Gf*), precipitation (*Pf*), and sediment delivery factors (*Df*). Cut-slope sediment is calculated using Equation 3 as a function of geologic erosion rate, cut-slope cover factor (*CSf*), cut-slope height (*CSh*), road length, and sediment delivery factor:

$$CS = GE_r CS_f CS_h L_r D_f \quad (3)$$

The road age factor (*Af*) refers to the maximum amount in the first or two years of road construction until the sedimentation that occurs due to the advancing age of the road is properly adapted by the cut-slope and fill-slope vegetation. In SEDMODL, the road age factor is 10 for the first year of construction and 2 for more than two years (Akay et al., 2008).

### 2.3. SEDMODL Application

The GIS database of the study area was generated by using ArcGIS 10.8 based on the digital data layers provided by Forestry Enterprise Directorate (road network, forest management map, topographical map, contour map) and by General Directorate of Mineral Research (geology map). Then, the digital data (10 m x 10 m) for each sediment factor was generated for each road segment.

Based on the data in the road network layer, new fields were generated for the road length, road width, road surface (native surface and gravel), road traffic factor and cut-slope cover factor for each road segment. The road lengths were calculated for each road segment in ArcGIS. The road width for gravel and native roads were 5 m and 3 m, respectively. Table 2-4 indicates the values of the road surface, traffic factor and cut-slope cover factor used in SEDMODL (Akay et al., 2008). The quality of the road surfacing material affects the sediment yield from the road tread surface. In the study area, surface types included gravel and native surface with the surfacing factors of 0.20 and 1.00, respectively. The sediment yield from a road tread surface is also affected by road use. The road classes in terms of road use were secondary road and spur road that have the traffic factors of 2.0 and 1.0, respectively. The cut-slope cover factor is defined as the percent of vegetation cover on cut-slope and cover factor increases as the percentage of vegetation cover decreases. In the study, forest management map was used to generate cover factor layer of the study area.

Table 2. Road tread surfacing factors for various common road surface types

| Surface Type | Surfacing Factor |
|---|---|
| Asphalt | 0.03 |
| Gravel | 0.20 |
| Pitrun | 0.50 |
| Grassed Native | 0.50 |
| Native surface | 1.00 |
| Native with ruts | 2.00 |

Table 3. Road traffic factors for road classes

| Road Classes | Road Descriptions | Traffic Factor |
|---|---|---|
| Highway | Main highway | 120 |
| Main Haul | Heavily used by log truck traffic throughout the year; usually the main access road in a watershed that is being actively logged | 120 |
| County Road | Wide, county-maintained road that receives heavy residential and log truck use | 50 |
| Primary Road | Receives heavy to moderate use by log trucks throughout the year. Usually, roads branching off main haul road that head up tributaries or that access large portions of the watershed | 10 |
| Secondary Road | Receives light log truck use during the year. May occasionally be heavily used to access a timber sale. Receives car/pickup or recreational use. | 2.0 |
| Spur Road | Short road used to access a logging unit. Used to haul logs for a brief time while unit is logged. On the average receives little use | 1.0 |
| Abandoned | Road is blocked by a tank trap, boulders, etc. or is no longer used by traffic | 0.1 |

Table 4. The cut-slope cover factors as a function of vegetation cover rates

| Vegetation Cover (%) | Cover Factor |
|---|---|
| 100 | 0.1023 |
| 70 | 0.2540 |
| 40 | 0.4435 |
| 10 | 0.7700 |
| 0 | 1.0000 |

The topographical map (1:25000 scale) was used to generate the stream map via the Hydrology tool in ArcGIS 10.8. In the SEDMODL, the sediment delivery factor for each road stage is estimated based on the distance from the middle point of the nearest stream to the middle point of the road stage. The SEDMODL assumes that a road segment at stream crossing directly delivers sediment to streams with a delivery factor of 100% while a road segment within 30 meters and 60 meters of a stream results a delivery factor of 35% and 10%, respectively. In this study, the sediment delivery factor for each road segment was determined based on the sediment delivery zones generated by using "buffer" tool in ArcGIS 10.8.

Digital Elevation Model (DEM), generated using contour map, was used to generate road grade, cut-slope height and precipitation factors. The road grade was computed for each segment using ArcGIS 10.8 based on the distance and elevation difference between the beginning and ending point of the road segment. In SEDMOL, the road grades less than 5%, between 5% and 10%, and more than 10% has the road grade factors of 0.2, 1.0, and 2.5, respectively. SEDMOL estimates the cut-slope height based on ground slope and the forest lands with steep hillside slope deliver more sediment. In this study, the slope map was generated based on the DEM and slope map was classified into four classes as suggested by SEDMODL (Table 5).

Table 5. The cut-slope height factor as a function of ground slope

| Ground Slope (%) | Cut-slope height factor |
|---|---|
| 0-15 | 0.75 |
| 15-30 | 1.50 |
| 30-60 | 3.00 |
| >60 | 7.50 |

The sediment yield from a road segment is greatly affected by the annual regional precipitation. In the SEDMODL, the precipitation factor is computed based on the average annual precipitation ($P_{avr}$ in mm) using Equation 4 (WFPB, 1997). The average annual precipitation can be estimated by using Schreiber method based on a meteorology station with known elevation and average precipitation (Erdoğan Yüksel and Karan, 2024). In this study, Uludağ Meteorological Station data and DEM was used to interpolate the average annual precipitation of the study area.

$$P_f = \left(\frac{P_{avr}}{1524}\right)^{0.8} \tag{4}$$

The sediment yield potential from a road segment also depends on soil properties and geological formation. In this study, the data layer of geological erosion factor was generated using the geology map at a scale of 1:250000 (MTA, 2011). The geologic age and lithology combination in the study area was Paleozoic and Schist with the erosion rate of 0.0148 ton per hectare (Akay et al., 2008).

Previously conducted studies on road erosion indicated that new roads have a much higher erosion rate than that of relatively old roads. In SEDMODL, road age factor is 10 in the first year of the road construction while it is 2 and 1 in the second year and more than second year, respectively. In this study, road age factor was considered as 1 as the roads in the study area were constructed more than 10 years ago.

## 3. Results and Discussion

Sedimentation resulting from road network in Gürgen Creek Watershed was estimated using GIS based SEDMODL considering the amount of sediment delivered from the road surface and from the cut slope. It was found that total length of the gravel and native roads were 4517 m and 390 m, respectively. The digital layers of factors including road surface, road traffic and cut-slope cover are indicated in Figure 2. DEM of the study area generated by contour map is shown in Figure 3. Finally, the data layers of delivery factor are indicated in Figure 5.

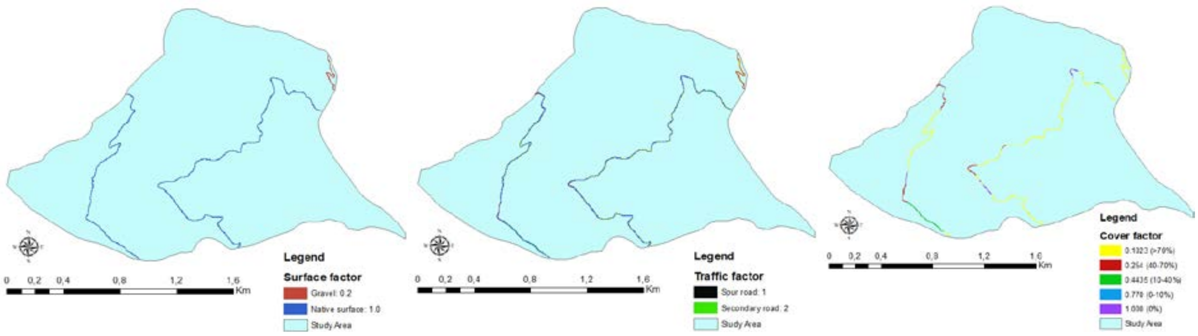



Figure 2. The digital layers of road surface (left), road traffic (middle) and cut-slope cover (right) factors

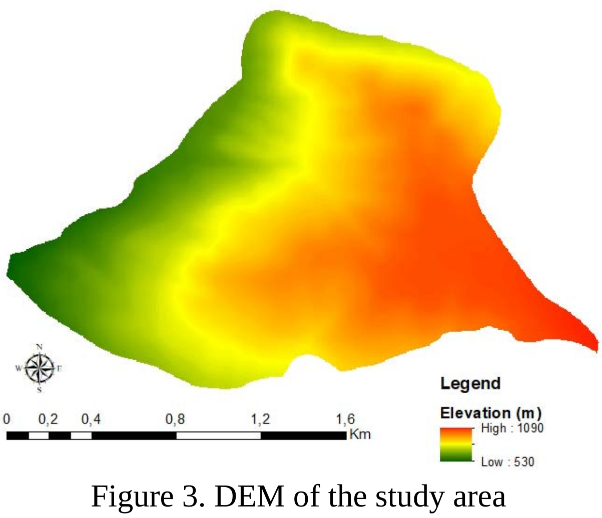



Figure 3. DEM of the study area

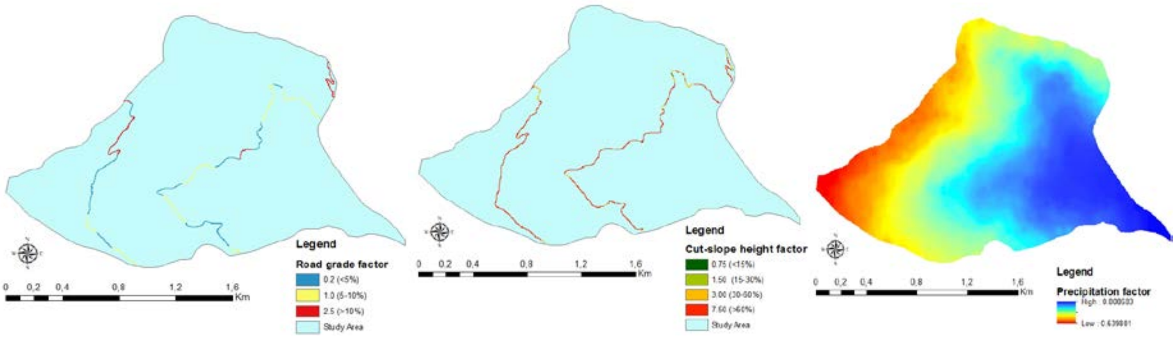



Figure 4. The digital layers of road grade (left), cut-slope height (middle) and precipitation (right) factors

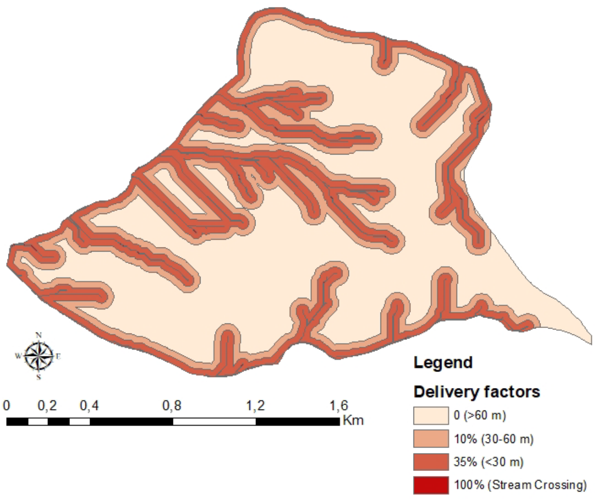



Figure 5. The digital layer of delivery factor

The total sediment delivery of the road network in the study area was estimated to be 160.86 tons (32.78 ton/km). Considering road types, 37.61 tons of the sediment were from gravel roads while the remaining 123.25 tons were from to the native surface forest road (Table 6). Thus, about 23.38% of the sediment were from gravel road while 76.62% was from the native surface forest road. The results obtained from this study was consistent with the results obtained in similar studies (Asadollahi et al., 2016; Farokhzadeh et al., 2017). Previous studies stated that the highest soil erosion rate was on forest roads with native surface (Akay et al., 2008).

Table 6. Sediment distribution according to roads.

| | Sediment (tons) | Length | Ton/Meter | Ton/Km |
|---|---|---|---|---|
| Gravel road | 37.61 | 390 | 0.096 | 96.429 |
| Native surface forest road | 123.25 | 4517 | 0.027 | 27.287 |
| Total | 160.86 | 4907 | 0.033 | 32.782 |

The results showed that the sediment yield from road sections largely depends on various erosion factors. Although their effects on sediment yield vary by road type (e.g., secondary or spar roads), the most important attributes to consider in estimating sediment yield are road use, road slope, and cut slope heights. Road width is another important factor that can significantly affect soil erosion and road degradation (Cao et al., 2021; Zhao et al., 2022). Narrow roads can cause intense runoff and erosion, leading to gully formation, while wide roads can increase the surface area of the road and reduce the speed of water, which can reduce soil erosion (Wang et al., 2022).

Suitable forest road network is crucial for sustainable management of forest resources; however, inadequately constructed and maintained forest roads can cause more environmental impacts than any of these activities. Road construction is one of the causes of various forms of erosion and sedimentation due to the destruction of vegetation, increased flow velocity and destabilization of the slope. This is especially important in forest watersheds due to environmental, ecological and economic impacts. In this study, average annual sediment yield from a road network to streams in a forest watershed was estimated by using the methodology of a GIS-based sediment prediction model, the SEDMODL model. GIS techniques were used to provide required data layers such as topography, streams, roads, geology, and average precipitation. The results indicated that the SEDMODL model integrated with GIS techniques can assist road managers to estimate total sediment yield quickly and effectively. Besides, critical road sections with high sediment yield potential can be identified and the efficiencies of various sediment control measures can be evaluated for these sections.

## 4. Conclusion

The sediment yield from a road network to streams in a forest watershed was estimated based on the methodology of the SEDMODL which is capable of identifying the road segments with high sediment yield potential. The results showed that the sediment yield from road sections depends on several erosion factors. The most important factors in predicting sediment yield were road use, gradient, and cut-slope heights. Based on the model outputs, road network can be evaluated in reducing sediment yield through a sensitivity analysis of the factors. Thus, road managers can quickly and efficiently evaluate the sediment yields from road network in large forest lands.

## References

Akay, A.E., Erdas, O., Reis, M., Yuksel, A. 2008. Estimating sediment yield from a forest road network by using a sediment prediction model and GIS techniques. Building and Environment. 43(5):687-695.

Asadollahi, Z., Yosefi, S., Mohammady, M. 2016. Sediment Yield Estimation Due to Forest Road Network Using SEDMDEL and GIS. J. Environ. Sci. Technol, 18(2):71-82.

Boise Cascade Corporation. 1999. SEDMODL-Boise Cascade road erosion delivery model. Technical documentation; 19 p.

Carl, S.C., Li, C. 2006. Impact of planting grass on terrene roads to avoid soil erosion. Landscape Urban Plan, 78(3):205-216.

Dalir, P., Naghdi, R., Gholami, V. 2014. Modelling of forest road sediment in the northern forest of Iran (Lomir Watershed). J. Forest Sci, 60(3):109–114.

Damain F. 2003. Cross-drain placement to reduce sediment delivery from forest roads to streams. University of Washington: U.S.A. 225 p.

Erdoğan Yüksel, E., Karan, Ö.F. 2024. Thornthwaite yöntemine göre iklim tiplerinin belirlenmesi: Bursa ili örneği. Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi, 25(1):151-168. DOI: 10.17474/artvinofd.1435376

Kastridis, A. 2020. Impact of forest roads on hydrological Processes. Forests, 11(11): 1-12.

Kastridis, A., Stathis, D. 2020. Evaluation of hydrological and hydraulic models applied in typical Mediterranean Ungauged watersheds using post-flash-flood measurements. J. Hydrol, 7(12): 1-24.

Ramos-Scharrón, C.E., LaFevor, M.C. 2016. The role of unpaved roads as active source areas of precipitation excess in small watersheds drained by ephemeral streams in the Northeastern Caribbean. J. Hydrol, 533(1):168–179.

Surfleet, C.G., Skaugset, A.E., Meadows, M.W. 2011. Road runoff and sediment sampling for determining road sediment yield at the watershed scale. Canadian J. Forest Resour, 41(10):1970-1980.

Toscani, P., Sekot, W., Holzleitner, F. 2020. Forest Roads from the Perspective of Managerial Accounting— Empirical Evidence from Austria. Forests, 11(4):1-15.

Wemple B.C., Browning T., Ziegler A.D., Celi J., Chun K.P., Jaramillo F., Leite N.K., Ramchunder S.J., Negishi J.N., Palomeque X., Sawyer D. 2018. Ecohydrological disturbances associated with roads: Current knowledge, research needs, and management concerns with reference to the tropics. Ecohydrol. 11: e1881.

WFPB. 1997. Washington Forest Practices Board Manual: standard methodology for conducting watershed analysis. V. 4.0.

# Analysis of Climate Change Variability Over Amasya Merzifon Forest Areas

**Mehmet Cetin***

Ondokuz Mayis University, Faculty of Architecture, Department of City and Regional Planning, Samsun, Türkiye
*mehmet.cetin@omu.edu.tr

## Abstract

Global climate change has widespread effects on forest ecosystems. This study aims to examine how climate change and changes in topography affect forest areas in the Amasya Merzifon region. The analysis covers changes in precipitation, surface temperature, vegetation condition, soil moisture, and drought indices from 2002 to 2021. The results indicate that average precipitation decreased by 49.21 mm over the 20-year period, while surface temperature increased by 9.01 ºC. The northern region was found to be the most affected, with these changes also being significantly felt in Merzifon, located in northeastern Amasya. Fluctuations in green area and moisture were predominantly noticeable in the northern regions. The SPEI values, based on the Google Earth Engine (GEE) platform, increased by -0.119. LST-based hot spot areas were observed in the southern and western parts of the region. The study revealed that reduced precipitation and high-temperature fluctuations could affect crop production, moisture loss, and lead to floods and droughts in the western regions.

***Keywords:*** *Temperature, precipitation, vegetation scenarios, SPEI, moisture content*

## 1. Introduction

Plant growth is heavily dependent on water, reflecting the relationship between land and atmosphere in terms of water, carbon, and energy exchange. Drought has a significant negative impact on terrestrial ecosystems, reducing the strength of carbon sinks and causing imbalances. The accelerated water cycle due to global warming is constrained by soil moisture, leading to limited water availability in the atmosphere. As droughts become more frequent, severe, and prolonged, they exacerbate water scarcity and negatively affect plant growth. However, it is unclear whether plants can adapt to changes in water availability under climate warming, which limits our understanding of the physiological mechanisms behind drought effects on plants (Novick et al 2016; Zeng et al 2017; Wang and Dickinson 2012; Jiao et al 2021; Shu et al 2021; Schumacher et al 2022; Lucht et al 2002; Gao et al 2023; Van Loon et al 2014; Wu and Chen 2019;  Yang et al 2022; Saifullah et al 2021).

Increased global vegetation cover and net primary productivity have led to higher water demand by plants, creating a positive feedback loop in ecosystems experiencing water scarcity. The relationship between plant growth and water availability becomes mutually restrictive, influenced by factors such as sudden droughts, urban heatwaves, and long-term low water supply. Drought has particularly harmful effects on vegetation, especially in high-altitude areas where water is not limiting, which may benefit plant function under climate change. Therefore, studying the relationship between vegetation dynamics and drought can enhance our understanding of plant sensitivity and resilience to drought under changing conditions (Novick et al 2016; Zeng et al 2017; Wang and Dickinson 2012; Jiao et al 2021; Shu et al 2021; Schumacher et al 2022; Lucht et al 2002; Gao et al 2023; Van Loon et al 2014; Wu and Chen 2019; Yang et al 2022; Saifullah et al 2021).

In Amasya Merzifon, drought development often coincides with warm periods, and even when rainfall occurs, it is challenging to prevent the destructive effects of drought on ecosystems during the growing season. Amasya Merzifon encompasses a large area with diverse vegetation, including grasslands, forests, and urban areas. Research indicates that agricultural lands show the greatest response to drought, followed by urban and rural areas, while forests exhibit strong resistance and resilience. This study analyzes the temporal and spatial dynamics of vegetation responses to drought across different seasons, identifies the most sensitive periods, and investigates the cumulative effects of drought and delayed plant responses. The findings have significant implications for ecological conservation and high-quality development in Amasya Merzifon.

## 2. Materials and Methods

Amasya Merzifon is a district located in the Black Sea Region of Türkiye, near the Inner Anatolian region. It is part of Amasya Province and is known for its historical and natural beauty. Key points include: Situated in the northern part of Amasya Province, close to the Black Sea and Inner Anatolian regions. Experiences a continental climate with hot, dry summers and cold, snowy winters. Heavy snowfall is common in winter. The surrounding forests are located in the eastern and northern parts of the district. They reflect both continental and coastal influences, impacting their ecological characteristics. The forests are crucial for maintaining the region's ecosystem balance and natural resources. They provide essential environmental functions and are important for conservation.

NDVI data were sourced from NASA's website with a spatial resolution of 1 km. These NDVI data were mosaicked and projected, with monthly data obtained from 2003 to 2020. SPEI data were calculated based on meteorological data. Gridded meteorological data were used for the calculation, with the SPEI classification outlined in Table 1. The calculation methods are detailed in Table 2.

Table 1. Classification of SPEI Index.

| Drought Grade | SPEI Value |
|---|---|
| Extreme drought | SPEI $\leq -2.00$ |
| Severe drought | $-2 <$ SPE I$\leq -1.5$ |
| Moderate drought | $-1.5 <$ SPEI $\leq -1$ |
| Mild drought | $-1 <$ SPEI $\leq -0.5$ |
| Normal | $-0.5 <$ SPEI $\leq 0.5$ |
| Mild wetting | $0.5 <$ SPEI $\leq 1$ |
| Moderate wetting | $1 <$ SPEI $\leq 1.5$ |
| Severe wetting | $1.5 <$ SPEI $\leq 2$ |
| Extreme wetting | SPEI $\geq 2$ |

Table 2. Correlation coefficient grading

| Level of CC | CC |
|---|---|
| **High positive correlation** | $0.8 \leq CC < 1.0$ |
| Strong positive correlation | $0.6 \leq CC < 0.8$ |
| Moderate positive correlation | $0.4 \leq CC < 0.6$ |
| Weak positive correlation | $0.2 \leq CC < 0.4$ |
| No correlation | $-0.2 \leq CC < 0.2$ |
| Weak negative correlation | $-0.4 < CC \leq -0.2$ |
| Moderate negative correlation | $-0.6 < CC \leq -0.4$ |
| Strong negative correlation | $-0.8 < CC \leq -0.6$ |
| High negative correlation | $-1 < CC \leq -0.8$ |

## 3. Results

From 2003 to 2020, the spatial pattern of SPEI showed notable heterogeneity. Forested areas generally exhibited lower SPEI values, while structural areas showed higher values. Extreme drought affected only 0.23% of the total area, primarily concentrated in the upper regions. Severe drought impacted 16.22% of the area, mainly affecting central plains and plateau regions, including cities and city groups. Moderate drought covered 41.2% of the area, predominantly in forested and upper regions. Mild drought affected approximately 37.12% of the area, mainly in upper regions, with drought-free areas constituting about 4.17% of the total area (Figure 1).

The analysis of SPEI's spatial trends in forest areas from 2003 to 2020 revealed a decreasing change rate from the basin's center to its periphery, with a five-level change rate. The highest reduction rate was concentrated in the plains and northern plateau, with a change rate of -0.9 to -1.5 per year, covering 16% of the total basin area. Surrounding areas showed decreasing change rates approaching zero. In forest source areas, plains, and urban areas, SPEI trends reversed, showing an increase with a rate of up to 0.9 over ten years, covering 21% of the basin area.

Temporal trends showed a decrease of -0.21 in SPEI over ten years, indicating a general drying trend across the basin. The range of SPEI changes was between -0.25 and 0.52. The years 2006 and 2013 experienced the most severe droughts with SPEI values of -0.12 and -0.21, respectively. A significance test found that SPEI change trends were significant in the plains, mountain valleys, and northern plateau areas, covering 9.25% of the basin area.

NDVI analysis from 2003 to 2020 showed a continuous increase of 0.022 per decade, indicating a rise in plant density or expansion of vegetation. NDVI values within the basin ranged from 0 to 0.92. The southern part of the basin had relatively better vegetation coverage, while the northwestern part, including high altitudes and the northwestern plateau, had lower coverage.

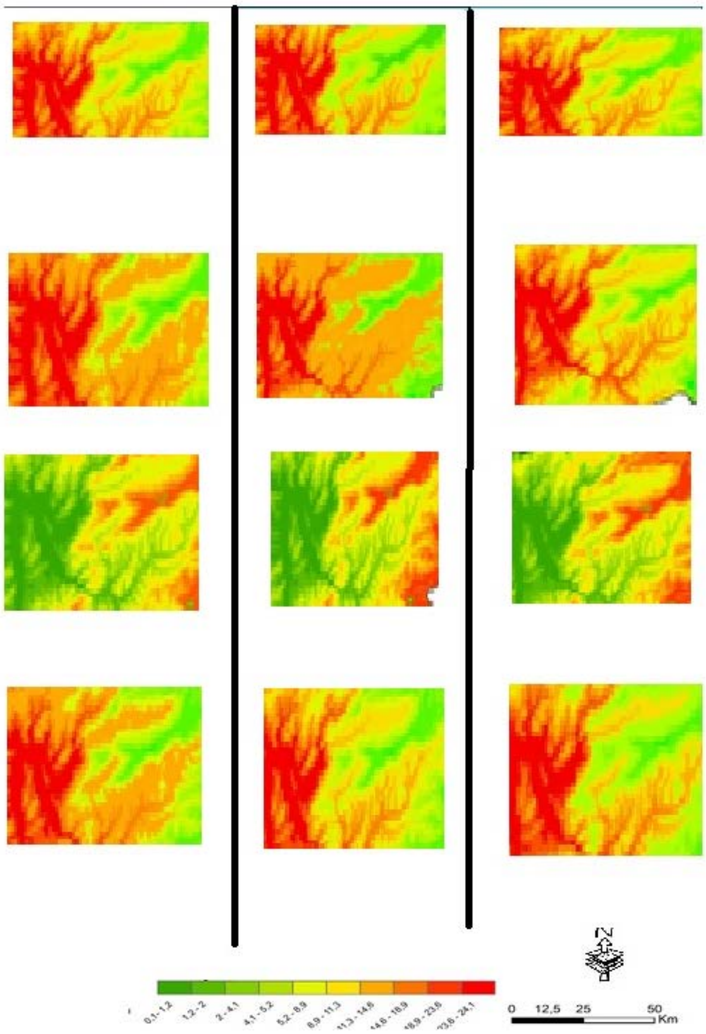



Figure 1. The spatial distribution of the CC between SPEI and NDVI

Monthly NDVI trends varied spatially. During winter (December to February), vegetation growth was slow, with significant reductions in NDVI in December and January. In February, NDVI recovery was observed due to rising temperatures. Spring saw a gradual increase in NDVI, covering up to 24% of the basin. In summer, significant NDVI areas decreased from 47% to 19% by August. Fall showed relatively stable NDVI increases, with significant reductions affecting 7-19% of the area. Notably, May, June, and July showed the most significant NDVI increases, reflecting improved vegetation growth and coverage.

## 4. Discussion

Drought has both severe and long-term effects on vegetation. Water scarcity slows down photosynthesis, causing leaf drying, shedding, and halting growth. Prolonged drought significantly impairs vegetation productivity and is a critical factor in plant death. Studies show that different ecosystems (e.g., grasslands and forests) exhibit varying sensitivities to water scarcity across seasons. The complex responses of vegetation to drought are shaped by the combined effects of water availability and thermal energy and are closely related to regional climates and plant types. Drought also dries and depletes soil, affecting plant growth and increasing susceptibility to diseases and pests. In ecosystems, drought can lead to reduced vegetation cover, soil degradation, and ultimately land desertification.

Recent studies indicate that increased evaporation demand has shortened the growing season of ecosystems. In summer, insufficient soil moisture cannot support rising atmospheric water demand, leading to suppressed evaporation and hindering plants' ability to meet higher evaporation needs. Thus, drought has a significant impact on vegetation, with serious implications for ecosystems and human societies.( Novick et al 2016; Zeng et al 2017; Wang and Dickinson 2012; Jiao et al 2021; Shu et al 2021; Schumacher et al 2022; Lucht et al 2002; Gao et al 2023; Van Loon et al 2014; Wu and Chen 2019; Yang et al 2022; Saifullah et al 2021)

Vegetation's response to drought reflects its resilience and recovery capacity. Short-term responses (3-6 months) are more sensitive, while long-term responses (12-24 months) indicate resilience and recovery. High elevations and steep slopes enhance vegetation's drought resistance, while flat areas show stronger recovery capacity. The order of vegetation mortality post-drought generally follows: temperate, subtropical, tropical, temperate, alpine climates; alpine regions are less affected by drought. In high-altitude regions, vegetation has stronger drought resistance and is less constrained by water. Atmospheric water demand increases evaporation, particularly in temperate regions, which may hinder vegetation growth. Although vegetation can mitigate drought effects, changes are mainly driven by climate change and rainfall variability. Climate warming extends the growing season in early spring and late autumn, reducing carbon sequestration benefits. Additionally, rising temperatures and afforestation will further increase the risk of drought spread.

## 5. Conclusions

Urbanization significantly influences the distribution of drought. Extreme drought mainly occurs in the central and upper areas, while severe drought is concentrated around the periphery, central region, and northern and southern parts of the area, characterized by nearby city clusters.

The spatial trend of the Standardized Precipitation Evapotranspiration Index (SPEI) shows a gradual decrease from the center and southern regions to the boundaries of the basin, with the most significant reduction in the basin's central plain and plateau. The reduction rate here ranges from -0.9 to -1.4 per decade, indicating a notable drought trend. In contrast, the source region, plain, and forest show an increasing trend in SPEI, with the highest increase rate reaching 0.9 per decade, indicating a shift towards reduced drought and increased moisture.

From 2003 to 2020, the Normalized Difference Vegetation Index (NDVI) exhibited an upward trend, suggesting increased vegetation density or expansion. The southern part of the basin, including the region, plain, west, and the southern part of the northern plain, has better vegetation coverage. Conversely, the northwestern part of the basin, including the highest elevation forest areas and the northwestern plateau, shows lower vegetation coverage.

Spring temperatures significantly impact plant growth, while the SPEI-driven water source exhibits increased sensitivity to plant growth. There is a positive correlation between drought and NDVI, peaking in July and gradually decreasing through August. Areas showing significant positive correlations are concentrated in the plateau region after passing rigorous significance tests. In autumn, the correlation between SPEI and NDVI continues to decrease, with more than 35% of regions showing weaker correlations. Additionally, during this period, SPEI has a more pronounced effect on NDVI compared to other periods, with winter showing the highest impact of SPEI on NDVI.

According to positive dynamic transmission laws at different levels, strong and moderate positive correlations show distinct transmission patterns, reaching their peak in July. The most noticeable positive effect on NDVI comes from SPEI. Among regions showing negative correlations between SPEI and NDVI, the effect of SPEI is most pronounced.

**References**

Novick, K. A., Ficklin, D. L., Stoy, P. C., Williams, C. A., Bohrer, G., Oishi, A. C., ... & Phillips, R. P. (2016). The increasing importance of atmospheric demand for ecosystem water and carbon fluxes. *Nature climate change*, *6*(11), 1023-1027.

Zeng, Z., Piao, S., Li, L. Z., Zhou, L., Ciais, P., Wang, T., ... & Wang, Y. (2017). Climate mitigation from vegetation biophysical feedbacks during the past three decades. *Nature Climate Change*, *7*(6), 432-436.

Wang, K., & Dickinson, R. E. (2012). A review of global terrestrial evapotranspiration: Observation, modeling, climatology, and climatic variability. *Reviews of Geophysics*, *50*(2).

Jiao, W., Wang, L., Smith, W. K., Chang, Q., Wang, H., & D'Odorico, P. (2021). Observed increasing water constraint on vegetation growth over the last three decades. *Nature Communications*, *12*(1), 3777.

Shu, Z., Jin, J., Zhang, J., Wang, G., Lian, Y., Liu, Y., ... & Jing, P. (2024). 1.5℃ and 2.0℃ of global warming intensifies the hydrological extremes in China. *Journal of Hydrology*, *635*, 131229.

Schumacher, D. L., Keune, J., Dirmeyer, P., & Miralles, D. G. (2022). Drought self-propagation in drylands due to land–atmosphere feedbacks. *Nature Geoscience*, *15*(4), 262-268.

Lucht, W., Prentice, I. C., Myneni, R. B., Sitch, S., Friedlingstein, P., Cramer, W., ... & Smith, B. (2002). Climatic control of the high-latitude vegetation greening trend and Pinatubo effect. *Science*, *296*(5573), 1687-1689.

Gao, Y., Fu, S., Cui, H., Cao, Q., Wang, Z., Zhang, Z., ... & Qiao, J. (2023). Identifying the spatio-temporal pattern of drought characteristics and its constraint factors in the Yellow River Basin. *Ecological Indicators*, *154*, 110753.

Van Loon, A. F., Tijdeman, E., Wanders, N., Van Lanen, H. J., Teuling, A. J., & Uijlenhoet, R. (2014). How climate seasonality modifies drought duration and deficit. *Journal of Geophysical Research: Atmospheres*, *119*(8), 4640-4656.

Wu, J., & Chen, X. (2019). Spatiotemporal trends of dryness/wetness duration and severity: The respective contribution of precipitation and temperature. *Atmospheric Research*, *216*, 176-185.

Yang, Y., Li, K., Wei, S., Guga, S., Zhang, J., & Wang, C. (2022). Spatial-temporal distribution characteristics and hazard assessment of millet drought disaster in Northern China under climate change. *Agricultural Water Management*, *272*, 107849.

Saifullah, M., Liu, S., Adnan, M., Zaman, M., Muhammad, S., Babur, M., ... & Wu, K. (2021). Assessment of spatial and temporal pattern of hydrological droughts in the upper indus basin, Pakistan. *Polish Journal of Environmental Studies*, *30*(5), 4633-4645.

# Assessment of Soil Contamination in Urban Forest Areas of Samsun City

**Ilknur Zeren Cetin**

Ondokuz Mayis University, Faculty of Architecture, Department of City and Regional Planning, Samsun, Türkiye
ilknur.cetin@omu.edu.tr

**Abstract**
Urban expansion and population growth have led to increased residential development, significantly affecting the quality of urban environments. One notable consequence of this expansion is the rise in soil contamination, which is attributed to both anthropogenic and industrial activities. Among the various pollutants, heavy metals in soil are of particular concern due to their industrial origins and potential health risks. Despite the wealth of research on heavy metal remediation, effective prevention and management of soil contamination remain critical due to the high costs and complexities associated with remediation processes. Urban green spaces, which serve as important recreational areas in cities, are especially vulnerable to soil contamination. This study focuses on assessing soil contamination in urban green spaces within Samsun City, with a particular emphasis on heavy metals like cadmium (Cd), lead (Pb), and phosphorus (P). Soil samples were collected from nine distinct locations across the urban area. Laboratory analyses determined the concentrations of these metals, and the data were subjected to statistical evaluations. Kriging interpolation techniques were employed to create detailed maps depicting the spatial distribution of heavy metal concentrations. The results highlight the pressing need for ongoing monitoring and management of soil contamination in urban green spaces to protect public health and minimize exposure to harmful pollutants.

***Keywords:*** *Urban forest area, soil contamination, Geographic Information Systems (GIS), heavy metals, statistical analysis*

## 1. Introduction

Urbanization is a global phenomenon characterized by the rapid expansion of cities and the increasing concentration of populations in urban areas. This transformation has profound implications for the environment, particularly with respect to soil quality and contamination. Urban areas are often subjected to various forms of pollution, with soil contamination emerging as a significant concern due to its potential impact on public health and the environment.

The process of urbanization involves the conversion of natural landscapes into built environments, which frequently leads to increased soil pollution. This contamination can result from numerous sources, including industrial activities, vehicular emissions, and waste disposal practices (García et al., 2019; Zhang et al., 2020). Industrial activities are known to release a variety of pollutants into the soil, including heavy metals such as cadmium (Cd), lead (Pb), and arsenic (As) (Alloway, 2013). These contaminants can accumulate in urban soils, leading to long-term environmental and health issues.

Heavy metals are toxic elements that can have detrimental effects on both environmental and human health. Cadmium (Cd), for instance, is a well-documented environmental contaminant that poses serious health risks, including kidney damage and bone loss (Kumar et al., 2017). Lead (Pb) exposure is associated with neurological and developmental impairments, particularly in children (Sparks et al., 2016). The persistence and mobility of these metals in soil make them a significant concern for urban environments, where they can easily affect areas frequented by people, such as parks and recreational spaces (Cui et al., 2008).

Urban green spaces, such as parks and recreational areas, provide essential ecological and social benefits. They offer recreational opportunities, contribute to mental well-being, and help mitigate urban heat islands (Tzoulas et al., 2007). Despite their importance, these areas are not immune to soil contamination. Research has demonstrated that even in urban parks, soil can be contaminated with heavy metals due to proximity to traffic and industrial activities (McGrath et al., 2014). The presence of contaminants in these areas poses risks to public health, particularly as these spaces are used for various activities, including sports and family gatherings (Feng et al., 2020).

Geographic Information Systems (GIS) have become an invaluable tool in environmental research, providing powerful capabilities for spatial analysis and visualization. GIS allows researchers to map the distribution of pollutants, identify contamination hotspots, and analyze spatial relationships between environmental factors (Khan et al., 2022). By integrating GIS with statistical methods, researchers can effectively assess and visualize soil contamination patterns, thereby informing management and remediation efforts (Peters et al., 2019).

As cities grow and develop, the environmental impacts of urbanization become increasingly evident. One critical issue is soil contamination, which arises from a variety of sources, including industrial activities and urban development. Heavy metals, such as cadmium (Cd) and lead (Pb), are of particular concern due to their toxicity and persistence in the environment. Urban green spaces, including parks and recreational areas, are essential for public health and well-being, yet they are not immune to contamination. This research aims to assess soil contamination in urban green spaces in Samsun City, using Geographic Information Systems (GIS) and statistical analysis to map and analyze heavy metal concentrations.

Soil pollution from industrial activities, traffic, and waste is a severe issue, with heavy metals like lead, cadmium, and copper being significant pollutants. These metals accumulate in soil, posing risks to both plant health and human well-being. Heavy metals negatively impact plant development and photosynthesis, with contamination typically highest at soil surfaces or shallow depths. The quality of urban environments, including green spaces, is crucial for public health. This study examines soil contamination in urban green spaces in Samsun City, focusing on heavy metals like cadmium (Cd), lead (Pb), and phosphorus (P). The analysis, using Kriging interpolation, highlights the need for ongoing monitoring and management to mitigate pollution and protect health.

## 2. Materials and Methods

As cities grow and develop, the environmental impacts of urbanization become increasingly evident. One critical issue is soil contamination, which arises from a variety of sources, including industrial activities and urban development. Heavy metals, such as cadmium (Cd) and lead (Pb), are of particular concern due to their toxicity and persistence in the

environment. Urban green spaces, including parks and recreational areas, are essential for public health and well-being, yet they are not immune to contamination. This research aims to assess soil contamination in urban green spaces in Samsun City, using Geographic Information Systems (GIS) and statistical analysis to map and analyze heavy metal concentrations.

This study aims to assess soil contamination in urban green spaces within Samsun City by focusing on the concentrations of heavy metals, specifically cadmium (Cd), lead (Pb), and phosphorus (P). Through the collection and analysis of soil samples from multiple locations, and the use of GIS and statistical methods for data interpretation, this research seeks to provide a detailed understanding of soil pollution in these critical areas. The ultimate goal is to highlight the importance of monitoring and managing soil contamination in urban green spaces to safeguard public health and enhance environmental quality.

The study area encompasses various urban green spaces within the city of Samsun. These locations were selected based on their accessibility and the level of public use. Soil samples were collected from nine distinct locations within the urban center. Each sample was collected at a depth of 15 cm to ensure consistency. The soil samples were analyzed for concentrations of cadmium (Cd), lead (Pb), and phosphorus (P) using standard laboratory techniques. Statistical analyses were performed to determine the concentration levels of the heavy metals. Kriging interpolation was applied to generate spatial distribution maps of the heavy metal concentrations. GIS software was used to visualize and analyze the data.

## 3. Results

Analyses were created using the Kriging interpolation method through ArcGIS software, as depicted in Figures 1. These figures illustrate the distribution map of the cadmium (Cd), lead (Pb), and phosphorus (P) element, highlighting areas of intense pollution in areas, along with the distribution of cadmium (Cd), lead (Pb), and phosphorus (P) elements (Table 1).

Area 1 shows high levels of Cadmium (Cd) at 166.2 Ppm and Phosphorus (P) at 577.95 Ppm, with moderate Lead (Pb) at 53.95 Ppm. The F Value for this area is 3.3**, indicating significant differences in contamination levels compared to other areas, though not the highest. The elevated Phosphorus levels could be attributed to nutrient accumulation or contamination, potentially impacting the ecological balance in this region.

In Area 2, the Cadmium levels are moderate at 93.45 Ppm, Lead levels are 48.7 Ppm, and Phosphorus levels are substantial at 370.95 Ppm. The F Value here is 3.6**, suggesting a moderate level of statistical significance in the differences observed. This area demonstrates noticeable variations in contamination levels, which are more significant compared to some other areas.

Area 3 exhibits high levels of Lead at 70.2 Ppm, with moderate levels of Cadmium (75.95 Ppm) and Phosphorus (447.45 Ppm). The F Value is 1.9**, reflecting less significant differences in contamination levels compared to other areas. Despite the high Lead concentration, the lower F Value implies that the differences in contamination may not be as impactful or statistically distinct.

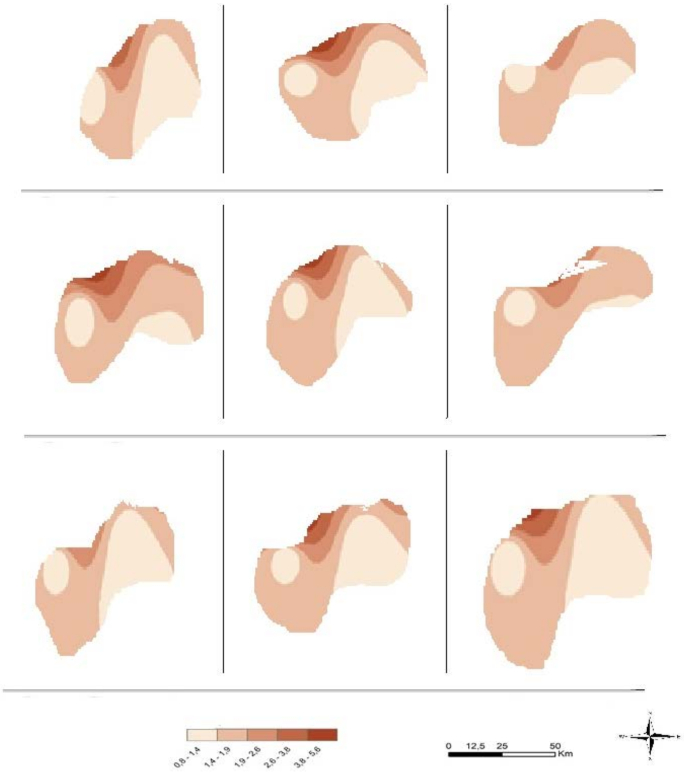



Figure 1 Map of the Element cadmium (Cd), lead (Pb), and phosphorus (P)

Table 1 presents the statistical analysis results regarding the regional variation of cadmium (Cd), lead (Pb), and phosphorus (P) element concentrations in the topsoil

| Area No | Cd (Ppm) | Pb (Ppm) | P (Ppm) | F Value |
|---|---|---|---|---|
| 1 | 166,2 Dg | 53,95 Bd | 577,95 Ci | 3,3** |
| 2 | 93,45 Cf | 48,7 Ej | 370,95 Be | 3,6** |
| 3 | 75,95 Ce | 70,2 Ce | 447,45 Aa | 1,9** |
| 4 | 168,2 Bc | 57,7 Dc | 327,45 Bb | 1,9 ** |
| 5 | 117,95 Cb | 59,2 Bb | 384,7 Dg | 7,8*** |
| 6 | 220,95 Dd | 61,7 Dg | 547,7 Ef | 1,8 ns |
| 7 | 138,45 Aa | 53,7 Bb | 283,95 Ce | 3,9** |
| 8 | 95,7 Bd | 47,2 Ce | 524,2 Df | 1,8** |
| 9 | 156,7 Ej | 53,7 Aa | 172,45 Ag | 3,9** |
| 10 | 137,95 Ce | 53,7 Bc | 254,2 Bc | 1,2** |
| F Value | 2,9* | 0,7 ns | 2,7 ns | 1,5** |

In Area 4, Cadmium levels are high at 168.2 Ppm, Lead is moderate at 57.7 Ppm, and Phosphorus is moderate at 327.45 Ppm. The F Value is 1.9**, indicating that despite the high contamination levels, the statistical significance of the differences is relatively low. This suggests that other factors may be influencing the contamination levels, or the variance is not as pronounced.

Area 5 shows moderate levels of Cadmium (117.95 Ppm) and Lead (59.2 Ppm), with high Phosphorus levels at 384.7 Ppm. The F Value is notably high at 7.8***, indicating very significant differences in contamination levels compared to other areas. This area exhibits pronounced statistical differentiation, suggesting substantial contamination effects.

In Area 6, Cadmium levels are the highest at 220.95 Ppm, with moderate Lead at 61.7 Ppm and high Phosphorus at 547.7 Ppm. Despite these high contamination levels, the F Value is 1.8 ns, which means the differences are not statistically significant. This could imply that the high contamination levels do not lead to significant statistical variance compared to other areas.

Area 7 has moderate Cadmium (138.45 Ppm) and Lead (53.7 Ppm), with lower Phosphorus levels at 283.95 Ppm. The F Value is 3.9**, indicating significant differences in contamination levels. The combination of moderate contamination and a higher F Value suggests that this area has notable statistical significance in its contamination profile.

In Area 8, the Cadmium level is moderate at 95.7 Ppm, Lead is low at 47.2 Ppm, and Phosphorus is high at 524.2 Ppm. The F Value is 1.8**, which suggests less significant differences despite the high Phosphorus levels. The variations in contamination levels are present but are not statistically distinct compared to other areas.

Area 9 displays high Cadmium levels at 156.7 Ppm, moderate Lead at 53.7 Ppm, and low Phosphorus at 172.45 Ppm. The F Value is 3.9**, reflecting significant differences in contamination levels. The combination of high Cadmium and Lead with lower Phosphorus results in considerable statistical differentiation.

In Area 10, Cadmium levels are moderate at 137.95 Ppm, Lead is 53.7 Ppm, and Phosphorus is lower at 254.2 Ppm. The F Value is 1.2**, indicating less significant differences in contamination levels. The contamination profile in this area does not stand out statistically compared to other regions.

Areas 5 and 7 exhibit the highest statistical significance with F Values of 7.8*** and 3.9**, respectively, indicating more pronounced differences in contamination levels. On the other hand, Areas 6 and 10, despite having high or moderate levels of contamination, show lower statistical significance (1.8 ns and 1.2**), suggesting that the variations in these areas may be less impactful or influenced by other factors. Areas 1, 2, 3, 4, 8, and 9 have moderate F Values, reflecting varying degrees of significance in their contamination profiles.

## 4. Discussion

The findings underscore the significance of monitoring soil contamination in urban green spaces. High levels of heavy metals pose risks to public health, especially in areas frequented by the public. The results suggest the need for targeted interventions to manage and mitigate soil contamination in these spaces.

This study assessed soil contamination in urban green spaces of Samsun City, focusing on cadmium (Cd), lead (Pb), and phosphorus (P). The results indicated significant variability in contamination levels, with elevated concentrations of Cd and Pb primarily in areas near major roads and industrial facilities. Phosphorus levels were higher in areas adjacent to municipal parks with frequent fertilizer use. These findings highlight the spatial variability of soil contamination and underscore the impact of urban activities on soil quality.

The concentrations of cadmium observed in this study, ranging from 1.2 mg/kg to 5.8 mg/kg, align with previous research indicating that urban soils, especially those near industrial and traffic areas, often have higher levels of cadmium (Cui et al., 2008; García et al., 2019). Cadmium is known for its persistence in soil and its potential to accumulate in plants, which can lead to adverse health effects in humans (Kumar et al., 2017). The elevated cadmium levels at Site 4, located near industrial areas, suggest that industrial emissions and activities are significant contributors to soil contamination. This finding is consistent with studies that have identified industrial activities as major sources of heavy metal pollution in urban environments (McGrath et al., 2014).

Lead concentrations in the sampled soils ranged from 45 mg/kg to 120 mg/kg, with the highest levels found at Site 7, which is near a major roadway. This result corroborates previous research highlighting the association between vehicular emissions and elevated lead levels in urban soils (Sparks et al., 2016; Zhang et al., 2020). Lead is a well-known environmental pollutant with serious health implications, including neurological and developmental effects, particularly in children (Feng et al., 2020). The spatial distribution maps generated through kriging interpolation revealed hotspots of lead contamination in areas with heavy traffic and industrial activity, reinforcing the need for targeted pollution control measures in these zones.

Phosphorus concentrations in the study ranged from 300 mg/kg to 600 mg/kg, with higher levels observed near parks with frequent fertilizer use. Elevated phosphorus levels in urban soils are often linked to the application of fertilizers and other soil amendments (Feng et al., 2020). While phosphorus is essential for plant growth, excessive levels can lead to nutrient imbalances and potential environmental issues, such as eutrophication in nearby water bodies (Alloway, 2013). The findings suggest a need for better management practices regarding fertilizer application in urban green spaces to mitigate potential environmental impacts.

The spatial analysis using GIS and kriging interpolation revealed distinct patterns of contamination, with higher concentrations of cadmium and lead concentrated in areas near industrial and traffic sources. This spatial variability highlights the impact of specific urban activities on soil quality and suggests that contamination is not uniformly distributed across the city. The correlation between cadmium and lead concentrations suggests a common source of contamination, likely related to industrial and vehicular emissions (Khan et al., 2022). The observed contamination levels, particularly at hotspots, pose significant health risks, emphasizing the importance of monitoring and managing soil quality in urban green spaces to protect public health.

The results of this study underscore the importance of integrating soil contamination assessments into urban planning and management strategies. Urban green spaces are crucial for providing ecological and recreational benefits, but their effectiveness can be compromised by soil pollution. Policies and practices that limit industrial emissions, reduce traffic-related pollution, and regulate fertilizer use are essential for maintaining soil quality in these areas (Peters et al., 2019). Additionally, regular monitoring and remediation efforts are needed to address contamination issues and ensure that urban green spaces continue to serve their intended purposes without posing health risks to the public.

## 5. Conclusions

Effective management of soil contamination in urban green spaces is crucial for protecting public health. This study provides valuable insights into the distribution of heavy metals in Samsun City and highlights the importance of ongoing monitoring and remediation efforts.

This study provided a comprehensive assessment of soil contamination in urban green spaces of Samsun City, focusing on cadmium (Cd), lead (Pb), and phosphorus (P). The analysis of soil samples from nine locations revealed significant variability in contamination levels, with elevated concentrations of Cd and Pb observed primarily near industrial and traffic-intensive areas. Phosphorus levels were higher in regions adjacent to parks with frequent fertilizer use. These findings underscore the spatial variability in soil contamination and its association with specific urban activities.

This study underscores the importance of addressing soil contamination in urban green spaces to ensure public health and environmental sustainability. By implementing effective pollution control measures, managing fertilizer use, and conducting regular monitoring, urban areas can better safeguard soil quality and maintain the benefits provided by green spaces. Collaborative efforts between policymakers, researchers, and the public are vital for achieving these goals and fostering healthier urban environments.

## References

Alloway, B. J. (2013). Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability. Springer.

Cui, Y., Zhu, Y. G., Zhai, R., Chen, D., Huang, Y., & Qiu, Y. (2008). Soil contamination and health risk assessment of heavy metals in urban parks. Journal of Environmental Sciences, 20(1), 38-47.

Feng, H., Zhang, Y., Zhang, J., & Xu, S. (2020). Health risk assessment of heavy metals in urban parks. Environmental Science and Pollution Research, 27, 36753-36762.

García, M. C., Martínez, A., & Fernández, J. A. (2019). Impact of urbanization on soil pollution: A review. Science of The Total Environment, 689, 232-245.

Khan, S., Cao, Q., Zheng, Y., Huang, Y., & Zhu, Y. (2022). GIS-based spatial analysis of soil heavy metal contamination and health risks. Environmental Monitoring and Assessment, 194(1), 1-15.

Kumar, A., Singh, R., & Tiwari, A. (2017). Cadmium toxicity and its mitigation in plants. Journal of Environmental Management, 203, 90-105.

McGrath, S. P., Zhao, F. J., & Dunham, S. J. (2014). Contamination of urban soils with heavy metals. Environmental Science & Technology, 48(8), 4208-4215.

Peters, A. J., Tiwari, D., & Ross, A. (2019). Application of GIS and spatial analysis in environmental management: A review. Environmental Science & Policy, 93, 125-135.

Sparks, D. L., & Menzies, N. W. (2016). Lead in the environment: Human health risks and remediation strategies. Environmental Pollution, 210, 199-207.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., & Kazmierczak, A. (2007). Promoting ecosystem and human health in urban areas using green infrastructure. Journal of Environmental Management, 84(3), 960-973.

Zhang, M., Wu, H., & Li, C. (2020). Industrial activities and soil pollution: An overview of recent studies. Environmental International, 140, 105762.

# Assessment of Compatibility of Forestry Machines with Soils Based on an Integral Indicator

**Yuliya Misuna*, Pavel Protas**

Belarusian State Technological University, Forest Roads and Timber Production Technology, Department of Logging Machinery, Minsk, Republic of Belarus
* julia.misuno@belstu.by

## Abstract
The forest fund of Belarus is characterized by a wide range of natural and production conditions. They can differ significantly among themselves in many indicators. The combination of these indicators forms the conditions for the design and subsequent implementation of logging operations, and also determines the goals and objectives of forest management. The current standards in the logging industry of Belarus, taking into account the accepted international obligations, require achieving a balance between the operational, economic and environmental interests of forest users. However, in practice, this is not always possible. Depending on the characteristics of a forest area, its development is carried out on the basis of the priority of specific goals, while the achievement of other tasks is secondary. In this case, the forest user is required to choose the most optimal technical and technological solutions for carrying out the relevant work in the forest. The key objective of the conducted research is to develop a method for assessing the compatibility of forest machine systems with soil conditions. This method is based on a comprehensive multi-criteria analysis of the parameters of interaction of forest machine movers with soils, taking into account operational, economic and environmental objectives of forest management. This method can become an important tool for effective planning and organization of logging operations.

***Keywords:*** *Compatibility, forest machines, method, criteria, integral indicator, forest management*

## 1. Introduction
Management of logging production as a whole and at its individual stages is a complex task that requires thoughtful planning, precise organization and, if possible, uninterrupted execution. The main difficulties arise at the stage of logging operations, on which depend the supply of raw materials and the functioning of forest industry enterprises, as well as subsequent stages of forest restoration and the high-quality development of future forests.

The production conditions for the development of forest resources may vary significantly depending on the natural and operational characteristics of forests, their category taking with account for economic, environmental and social significance, weather and climate factors, applied technological processes and the available technical equipment of enterprises, the policy pursued with respect to forests and their resources, etc. The listed characteristics determine the conditions that must be make provision for when designing and implementing the technological process of logging operations. They also form the tasks of forest management, i.e., the results that must be achieved during logging operations and after their implementation are determined.

In general, the formation of forest management tasks should be carried out in accordance with the principles and requirements of sustainable forest management and forest use. This means that when developing forest resources, a balance must be maintained between the technical capabilities of the enterprise, economic costs and environmental impact. But in real conditions, achieving this balance can be extremely difficult. Often, practitioners are required to make decisions that will be based on achieving key economic and operational objectives of forest management. And in this case, environmental standards or requirements of regulatory documents become secondary.

In Belarus, such difficulties are encountered when developing difficult accessible water-logged areas of the forest fund. These territories, which are sensitive to external influences during logging operations, have been of increased interest to loggers in recent years. This is due to the significant volumes of softwood raw materials, the sale of which in harvested form is possible outside of exchange trading, which is an additional incentive for their procurement. The technologies and specialized logging equipment currently used are largely capable of ensuring the development of difficult accessible water-logged areas. However, it is necessary to take into account that their use or the development of new technical solutions for the development of these areas should be carried out based on the principles of technical efficiency, economic feasibility and meeting environmental safety requirements, since, for example, the consequences of soil damage during logging are long-term and manifest themselves in a decrease in the productivity of future forest stands over several decades (Ilintsev et al., 2018; Bartenev, 2014; Dymov, 2017; Dymov et al., 2021).

Most studies assessing the feasibility of using forestry machines in various conditions focused on specific parameters of machine interaction with the environment in which they were operated. The most common areas of research concerned changes in soil conditions, damage to root systems and growing forest stands (Rollerson, 1990; Pirnazarov, 2015; Poje et al., 2019). The influence of soil characteristics on the flotation of forestry machines and their traction and coupling properties was analyzed separately (Agejkin, 1972; Stoilov and Marinov, 2009; Cudzik et al., 2018). In general, these studies formed possible ranges of conditions for using forestry machines with certain technical characteristics, taking into account specific operational or environmental parameters of interaction with the environment.

At the same time, a number of studies contain approaches and methods that allow for a comprehensive assessment of the compliance of forest machine parameters with the economic conditions of their use and forestry and environmental requirements (Fedorenchik et al., 1999; Katarov, 2009; Lutsenko and Ryabukhin, 2006; Fedorenchik, 2013). If we consider the presented research results, we can note that they definitely have practical application. However, their task is to assess or compare machine systems according to individual indicators or a certain group of criteria, united by requirements for ensuring the movement of forest machines and / or their compliance with forestry and environmental standards. In this paper, the goal was to develop a method for assessing the compatibility of forest machines with soils based on a complex integral indicator. This approach will allow for a comprehensive assessment of the applicability of forest machines in logging operations, taking into account the key factors that determine the feasibility and effectiveness of using various machine system options.

## 2. Material and Methods

### 2.2. Criteria for assessing the compatibility of forestry machines with soils

A reasonable and objective assessment of forest machinery compatibility with soils can be carried out on the basis of a thorough analysis of data that characterize not only the main components of the forest fund development process: a forest machine, forest soils as a determining indicator of the conditions for performing work, as well as the technology and organization of logging operations. Parameters that characterize their interaction with each other should also be defined and taken into account. So, soil conditions have a significant impact on the traction and coupling properties of logging equipment, which is manifested in changes in the speed of movement, flotation ability, maneuverability, etc. At the same time, logging equipment also has a negative impact on the soil, which can result in the destruction of its structure and a change in its physical, mechanical and biological properties. The technological process and the organization of work in the logging area will be determined, among other things, based on soil conditions, on the basis of which machines with certain parameters of the mover will be selected for their implementation. Subsequently, the designed technology may include various measures that will ensure the efficient operation of machines, as well as the minimization of damage to the soil.

The essence of the developed method is a comprehensive assessment of the influence of soil conditions, parameters of the mover and the technological process of harvesting timber on the parameters of interaction of forest machines with soils. As a result, the correlation between the forest machine, forest soil and technology were determined based on the conditions and parameters of their interaction. In this study, the interaction parameters are presented in the form of a system of criteria by which the operational, environmental and economic compatibility of forest machines with soils is assessed:

– machine flotation ability;
– mover pressure on the soil;
– machine productivity utilization factor;
– soil density after loading;
– track depth;
– mineralization degree;
– timber harvesting costs.

Evaluation of the compatibility of forest machines with soils according to these criteria allows us to determine the possibility of using the machine, taking into account its operational efficiency in certain soil conditions, the economic feasibility of developing the forest fund and the possibility of complying with forestry and environmental requirements (Protas and Misuna, 2016).

Determination of these criteria based on the available data on the characteristics of forest machines, forest soil and the technological process is not the final stage of compatibility assessment. An important component of the analysis of actual values of the criteria is their comparison with the permissible values of the criteria. Conformity of the parameters of interaction of forest machines with soil to the permissible values of the criteria will fully facilitate the fulfillment of tasks to ensure the efficient operation of machines in the felling area and the preservation of productivity and favorable conditions for subsequent reforestation.

**2.2. Justification of acceptable values of criteria**

Within the framework of the developed method for assessing the compatibility of the studied machines with forest soils, it is necessary to determine the quantitative boundaries of their permissible interaction. This implies the definition and justification of the permissible values of the compatibility criteria.

Permissible values of criteria can be established on the basis of current requirements of technical regulatory and legal acts, based on the results of previously conducted theoretical and experimental studies, development production observations, etc. At the same time, the values of these criteria will also be determined on the basis of the conditions and objectives of logging operations.

For practical application of these acceptable criteria values, it is proposed to use an acceptability scale. An example of such a scale is presented in Table 1.

Table 1. Acceptability scale of criteria for assessing compatibility of forestry machines with soils

| Criteria | Assessment of compliance with acceptable conditions | | | |
|---|---|---|---|---|
| | Unsatisfactorily | Satisfactory | Good | Full well |
| Machine flotation ability (coefficient of resistance to movement) | 0.25–0.3 | 0.21–0.24 | 0.1–0.2 | 0–0.09 |
| Track depth, m | 0.26–0.6 | 0.21–0.25 | 0.11–0,2 | 0–0.1 |
| Mover pressure, kPa | 121–200 | 81–120 | 61–80 | 20–60 |
| Soil density after loading, $g/cm^3$ | 1.9–2.8 | 1.5–1.89 | 1.2–1.49 | 0.7–1.19 |
| Degree of mineralization, % of felling area | 36–50 | 26–35 | 21–25 | 5–20 |
| Machine productivity utilization coefficient | 0–0.29 | 0.3–0.59 | 0.6–0.89 | 0.9–1.0 |
| Costs of harvesting, U.S. $dollar/m^3$ | 50–65 | 35–49 | 25–34 | 15–24 |

This scale version can be used in designing final fellings. The numerical limits of the qualitative assessments "Good" and "Satisfactory" correspond to the permissible values of interaction of forest machine movers with soils. According to a number of criteria, the studied machine variants can be allowed with a satisfactory assessment of interaction if their use is considered, for example, in difficult accessible water-logged areas of the forest fund. Tightening the requirements for permissible impact may lead to the fact that none of the considered machine variants can be used for the specified conditions.

Under other conditions and methods of forest management (intermediate felling, clearing of wind-damaged forest areas, felling in protective forests, etc.), a separate scale of permissibility is required, in which the corresponding permissible values of the criteria and boundary conditions for the use of forest machines will be established.

**2.3. Analysis of compatibility criteria of forest machines with soils**

The analysis of actual and acceptable values of criteria is an important stage in substantiating the choice of a machine system for the development of forest fund areas and the necessary measures for the implementation of the adopted technological process of logging operations in specified conditions. A reasonable and comprehensive assessment of the compatibility of forest machines with soils requires the use of a method that will take into account the actual values of all compatibility criteria, their significance depending on the conditions and purposes of forest management, as well as make a comparative assessment of several alternative machine options for work in specified conditions (Blagojević, 2019).

Therefore, the use of **the integral assessment method** is proposed. This is a method of comparative analysis and assessment of the compatibility of the studied machines based on a complex integral indicator (Misuna, 2023).
**An integral indicator** is a value that allows one to take into account and combine all the main characteristics of the objects or processes being studied, and present them in a single numerical value.

To take into account the importance of criteria, it is proposed to use criteria ranking, which allows determining the overall compatibility indicator of the machine in question or several machine options, taking into account the degree of importance or weight of each criterion based on its attractiveness relative to other criteria. Ranking includes setting a weighting coefficient that corresponds to an assessment in a given interval. The assessment is performed by an expert or a decision maker based on their knowledge, experience and intuition. Separate calculation methods can also be used to determine the weighting coefficient. For example, the value of the weighting coefficient for each criterion can be determined using Fishburn's rule (Makarova, 2015):

$$\omega_j = \frac{2 \cdot (n_c - j + 1)}{n_c \cdot (n_c + 1)}, \tag{1}$$

where $n_c$ is the number of criteria; $j$ is the rank of the criterion.

Considering that the criteria under consideration have different ranges of values and dimensions, for further calculations they must be brought to a single form and dimensions must be eliminated. This process is called criteria normalization. In this case, they are brought to relative values, usually using natural normalization. This approach allows you to obtain the value of the evaluation criterion relative to the reference value. When minimizing the evaluation criterion, normalization occurs according to the following relationship (Carev, 2002; Barkalov et al., 2020):

$$k_i^* = \frac{k_i - k_i^{\min}}{k_i^{\max} - k_i^{\min}}, \tag{2}$$

when maximizing:

$$k_i^* = \frac{k_i^{\max} - k_i}{k_i^{\max} - k_i^{\min}}, \tag{3}$$

where $k_i$ is the actual value of the criterion; $k_i^{\min}$ is the minimum (reference or acceptable) value of the $i$-th criterion among the compared options; $k_i^{\max}$ is the maximum (reference or acceptable) value of the $i$-th criterion among the compared options.

To derive a complex integral indicator, a convolution of normalized criteria is performed:

$$\mathrm{CII} = \sum_{i=1}^{n} \omega_i k_i^*, \tag{4}$$

The one that received the highest value of the integral indicator is accepted as the most acceptable alternative.

The algorithm of multi-criteria analysis based on the integral indicator for comparison and selection of the most acceptable variant of a forest machine or machine system is presented in Figure 1.

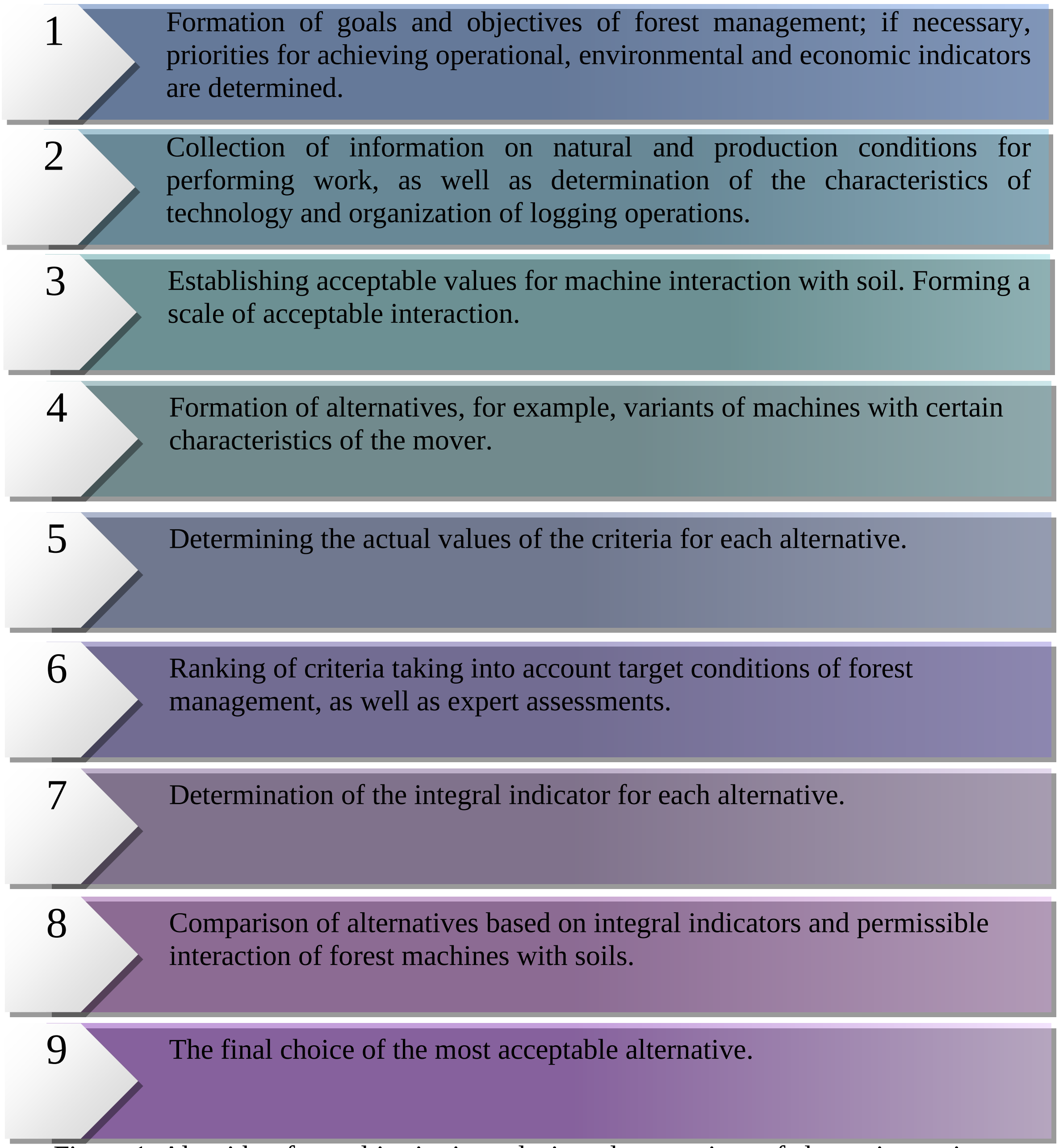


Figure 1. Algorithm for multi-criteria analysis and comparison of alternative options

This decision-making method based on the presented algorithm allows us to quantitatively and, in some cases, qualitatively assess the compatibility of forest machines with soils, compare different machine options with each other and determine the degree of their compliance with the specified boundary conditions from the point of view of the goals and objectives of forest management.

**3. Results**

To test the presented method, we will consider the following examples of forest machine compatibility assessment depending on the type of felling: clearcutting final felling, non-clearcutting final felling and intermediate felling. The conditions and tasks of forest management for these types of felling differ. The ranking options for the accepted compatibility criteria are presented in Table 2.

Table 2. Ranking of criteria for compatibility of forest machines with soils

| Criteria | Rank/weight of criteria by forest management types | | |
|---|---|---|---|
| | Clearcutting final felling | Non-clearcutting final felling | Intermediate felling |
| Machine flotation ability (coefficient of resistance to movement) | 3 / 0.18 | 1 / 0.25 | 5 / 0.11 |
| Track depth | 4 / 0.14 | 3 / 0.18 | 3 / 0.18 |
| Mover pressure | 5 / 0.11 | 2 / 0.21 | 1 / 0.25 |
| Soil density after loading | 6 / 0.07 | 4 / 0.14 | 2 / 0.21 |
| Degree of mineralization | 7 / 0.04 | 5 / 0.11 | 4 / 0.14 |
| Machine productivity utilization | 2 / 0.21 | 6 / 0.07 | 6 / 0.07 |
| Costs of harvesting | 1 / 0.25 | 7 / 0.04 | 7 / 0.04 |

An example of normalization of the actual values of the compatibility criteria of the machines under consideration for work in final felling areas is presented in Table 3.

Table 3. Normalization of actual values of criteria for the studied machine variants

| Criteria | Actual/normalized criteria values | |
|---|---|---|
| | Forwarder Amkodor 2661-01 | Forwarder Ponsse Buffalo |
| Machine flotation ability (coefficient of resistance to movement) | 0.25 / 0.17 | 0.24 / 0.2 |
| Track depth, m | 0.2 / 0.67 | 0.1 / 0.83 |
| Mover pressure, kPa | 125 / 0.38 | 85 / 0.58 |
| Soil density after loading, g/cm$^3$ | 2,5 / 0.14 | 2.1 / 0.33 |
| Degree of mineralization, % of felling area | 35 / 0.4 | 25 / 1 |
| Machine productivity utilization coefficient | 0.5 / 0.5 | 0.75 / 0.75 |
| Costs of harvesting, U.S. doll./m$^3$ | 37.5 / 0.55 | 42.2 / 0.46 |

Using formula (4), we obtain the integral indicator for the two compared machine variants:

$$\mathrm{CII}_{\text{option 1}} = 0,17 \cdot 0,18 + 0,67 \cdot 0,14 + 0,38 \cdot 0,11 + 0,14 \cdot 0,07 + 0,4 \cdot 0,04 +$$
$$+ 0,5 \cdot 0,21 + 0,55 \cdot 0,25 = 0,43,$$
$$\mathrm{CII}_{\text{option 1}} = 0,2 \cdot 0,18 + 0,83 \cdot 0,14 + 0,58 \cdot 0,11 + 0,33 \cdot 0,07 + 1 \cdot 0,04 +$$
$$+ 0,75 \cdot 0,21 + 0,46 \cdot 0,25 = 0,55.$$

The maximum possible value of the integral indicator can be equal to 1. As a result, it is clear that the second version of the machine is more suitable for work on Clearcutting final felling on waterlogged soils than the first. Moreover, the second version is 12% better than the first, but for the given conditions it is suitable only by 55%.

## 4. Conclusion

The method for assessing the compatibility of forest machines with soils presented in this study is a universal decision-making tool for planning and organizing logging operations. Its application has no limitations in terms of volumes and types of forest felling, operating conditions of forest machines, the number and content of the alternative options under study.

In addition, at each stage of the assessment using the developed method, it is possible to make changes and additions taking into account the specifics of production. So, the system of criteria can be supplemented, other boundaries of permissible interaction of machines with forest soils can be defined, other ranking methods for the criteria under consideration can be established.

The key feature of the developed method is the ability to make a well-founded and reasoned decision using numerical integral indicators. At the same time, the accuracy and reliability of the choice of machine systems lies in the use of various criteria, including technical, environmental and economic evaluation indicators, which allows for the implementation of the principles of sustainable forest management and forest use when choosing machines.

## References

Agejkin, Ya.S. 1972. All-terrain wheeled and combined movers. Edited by Mechanical engineering, Moscow. 184 p.

Barkalov, S.A., Glushkov, A.Yu., Moiseev, S.I. 2020. Mathematical methods of multi-criteria assessment of project attractiveness. Bulletin of SUSU. Series "Computer technologies, control, radio electronics". Vol. 20. 1: 111-119. DOI: 10.14529/ctcr200111.

Bartenev, I.M. 2014. Energy-saving and nature-saving technologies in the forestry complex. Edited by Ministry of Education and Science of the Russian Federation, Federal State Budgetary Educational Institution of Higher Professional Education "VSUFT". Voronezh. 107 p.

Blagojević, B., Jonsson, R., Björheden, R., Nordström, E-M.., Lindroos, O. 2019. Multi-Criteria Decision Analysis (MCDA) in Forest Operations – an Introductional Review. Croatian Journal of Forest Engineering. 40: 191-205.

Carev, V.V. 2002. Intra-company planning. Edited by Piter, Saint Petersburg. 493 p.

Cudzik, A., Brennensthul, M., Białczyk, W., Czarnecki, Ja. 2018. Tractive Performance of Tyres in Forest Conditions – Impact Assessment of Ground and Tyres Parameters. Croatian Journal of Forest Engineering. 39: 85-96.

Dymov, A.A. 2017. The Impact of Clear-Cutting in Russian Boreal Forests on Soils (Review). Soil Science. 7: 787-798. DOI 10.7868/S0032180X17070024.

Dymov, A.A., Starcev, V.V., Kutyavin, I.N., Dubrovskij, Yu.A., Bokov, I.A. 2021. Changes in podzolic soils of the Southern Timan under the influence of wheeled logging equipment during summer logging. VIII Congress of the V.V. Dokuchaev Soil Science Society and the School of Young Scientists on Soil Morphology and Classification "Soils - a Strategic Resource of Russia". 22 April, Moscow-Syktyvkar (Russia).

Fedorenchik, A.S., Merkul', V.G., Sokolovskij, I.V. 1999. Typification of forest areas of Belarus for the development of requirements for the organization and implementation of logging operations. Proceedings of BSTU. Ser. 2. 8: 8-12.

Fedorenchik, A.S. 2013. Assessment of the applicability of Amkodor forestry machines. Proceedings of BSTU. № 2 (158): 10-13.

Ilintsev, A., Nakvasina, E., Aleynikov, A., Tretyakov, S., Koptev, S., Bogdanov, A. 2018. Middle-term changes in topsoils properties on skidding trails and cutting strips after long-gradual cutting: A case study in the boreal forest of the North-East of Russia. Croatian Journal of Forest Engineering. 39: 71-83.

Katarov, V.K. 2009. Justification of the applicability of technological processes of logging operations according to the degree of impact on the primary transport routes. Ph.D. Thesis, Petrozavodsk (Russia). 123 p.

Lucenko, E.V., Ryabuhin, P.B. 2006. To determine the applicability of forestry machine systems. Current problems of the forest complex. 16: 23-26.

Makarova, I.L. 2015. Analysis of methods for determining weighting coefficients in the integral indicator of public health. Symbol of science. 7: 87-94.

Misuna, Yu.I. 2023. Application of multi-criteria analysis methods for assessing the operational and environmental compatibility of forestry machines with soils. VI International Scientific and Technical Conference "Technological Independence and Competitiveness of the Union State, CIS, EAEU and SCO Countries". 6-8 December. Minsk (Belarus).

Pirnazarov, A.U. 2015. Forestry technology and soil interaction for sustainable forestry. Ph.D. Thesis, Stockholm (Sweden). 54 p.

Poje, A., Mihelić, M., Leban, V. 2019. Analysis of Professional Assessment of Forest Soil Damage. Gozdarski Vestnik. Vol. 77. 1: 3-20.

Protas, P.A., Misuna, Yu.I. 2016. Structural diagram and criteria for assessing the operational and environmental compatibility of forestry machines with soils. / Proceedings of BSTU. 2 (184): 248-253.

Rollerson, T.P. 1990. Influence of Wide-Tire Skidder Operations on Soils. Journal of Forest Engineering. Vol. 2. 1: 23-30.

Stoilov, S., Marinov, K. 2009. Analysis of Four-Wheel-Drive Skidder Efficiency of Motion. FORMEC. 21-24 June. Prague (Czech Republic).

# Modelling of Gas Dispersion in Forests and Usage of Actual Dispersion Models in Forest Areas: A Software Assisted Study of a Likely Outflow Scenario

**H. Hulusi Acar, Tahsin Aykan Kepekli***

[1]Istanbul Yeni Yuzyil University Occupational Health and Safety Department, Faculty of Health Sciences, Istanbul, Türkiye
*Corresponding author e-mail: aykanke@gmail.com

**Abstract**
Forests are one of the few areas in where most of the risk factors associated with Occupational Health and Safety can be observed. From mechanical and physical risk to biologics and chemicals almost all the factors do have relevance in applied forestry works. Separately, in recent years and the latter half of the past century, one of the biggest hazards for public and environmental safety has been major industrial hazards. These events: characterized as very large industrial fires, explosions or gas dispersion events posed a great threat for civilization and environment in general throughout the world. Some of these hazards came to be realized as real events which showed its effects in disaster proportions like Bhopal (1984) disaster. Gas dispersions like these still pose a great danger as many hazardous chemicals are used in industrial applications. Forestry works, although at first glance seem to be devoid of such large chemical usage and storage, still include such facilities where these chemicals may pose a danger. Aside from risk of fire there is also a risk of gas dispersion from usage of hazardous chemicals like pesticides, fuels, fertilizers etc. Although for open fields and urban areas, dispersion of such chemicals has been studied extensively in the past, there are very few studies that investigate the outcome of a dispersion event in a forest area. For this purpose, several devised chemical outflow and dispersion scenarios were structured and modelled using EPA-NOAA ALOHA software's dispersion modules. The results were correlated as distance to gas concentration outcomes and were graphed accordingly. Also, the results were shown on the scenario area map using Google Earth software with map contours chosen for specific EPA concentration levels such as AEGL1-2-3. When modelling the scenarios one of the most important inputs that would affect the results in forests is the Roughness Ratio number. In this study these numbers were chosen according to most probable and likely ratios present in actual forests of Istanbul – Türkiye. This innovative approach to applied risk assessment in forest dispersion events is thought to be a showcase approach which may shed light to such future studies in the same field.

***Keywords:*** *Occupational health and safety in forestry, gas dispersion, environmental risks in forestry*

## 1. Introduction

Forestry works are usually counted amongst sectors where hazardous chemicals are encountered and used. These chemicals bring with them their risks in case of exposure to them via inhalation, skin absorption or swallowing. Such risks can be very hazardous like very toxic just as well as they can be relatively less hazardous like irritant. Chemicals like pesticides, fuels and fertilizers are some of the widely used in forestry works. Some examples are: Chainsaws and vehicles constantly emit exhaust gas – smoke; there is a risk of fire due to the combustion of fuel and other flammables. The combustion product can be hydrocarbons and smoke emit; chemicals are used for spraying (glyphosate, triazine, organophosphates, etc.) Pesticides can have toxic effects; appropriate respiratory protectors should be used in these applications. To prevent the contact of chemicals with the skin, it is necessary to use protective equipment to prevent skin contact. In addition, chain – machine oil decomposition and respiratory tract irritation and other ailments may occur in the long-medium term with these gases. Skin irritation is involved with skin exposure during maintenance (Health and Safety in Forestry Guide, Risk Assessment Check List in Log Production Works).

In assessing the risks of the chemicals in any type of work activity, the first usual step is to determine the hazard categorization and this requires an investigation of references like its Safety Data Sheet (SDS) or international databases. However, some chemicals may have unknown properties that have not been found in previous research and may be absent in results of a targeted search for specified risks; in which case it would be required to determine the chemical and physical characteristics of that chemical before an assessment can even begin.

Throughout history (especially from the start of $20^{th}$ century onwards) there have been many major industrial accidents which have resulted from faulty usage or storage of hazardous chemicals. Exposure to these chemicals during such accidents can be minimal in a local event with limited spread, however if the discharged amount is large it can result in an event that may cover wide areas and affect a greater number of populations through exposure. Accidents like Bhopal (1984) or Seveso (1976) are examples of such widespread spills that have covered large areas and affected local populations in the most harmful ways possible resulting in devastating losses. Such widespread chemical discharges are usually encountered as the dispersion of a chemical in gaseous or aerosol phases originally in the form of a cloud travelling downwind along a trajectory and exposure happens in the areas where this cloud passes through (Homberger et. al., 1979; Mannan, 2012).

The aim of this study is to investigate the effects of dispersion events in forest areas. Although for open fields and urban areas, dispersion of such chemicals has been studied extensively in the past, there are very few studies that investigate the outcome of a dispersion event in a forest area. Therefore, it is thought that the results of this study will be helpful in future studies about this phenomenon and understanding the risks of gas dispersion events in forest areas.

## 2. Materials and Methods

The most important result in a chemical disaster risk assessment is to find out what kind of toxicity effects will the dispersion have at what ranges. Depending on the density a gas cloud may go up if it is less dense than air or move while staying on the ground levels. The latter is riskier and most gases like pesticides are like this, they are denser than air. Atmospheric stability plays a key role in dispersion. As night conditions prevail the atmosphere is stable and gas clouds are able to travel farther before mixing with the air. Therefore, a nighttime event is riskier than a daytime spillage event. With empirical or CFD methods the gas concentration is calculated at distances relative to the event's point of origin. Then with help of software these are interpreted to real coordinates where the event is studied to occur (Ermak, 1990; Mannan, 2012).

Within the scope of the Consequence (effects) Analysis studies, ALOHA software, which is the hazard modelling component of the CAMEO software team developed by NOAA® (National Oceanic and Atmospheric Administration) and EPA (U.S. Environmental Protection Agency) was used.

ALOHA (Areal Locations of Hazardous Atmospheres) is a software designed for emergency response and planning professionals to model chemical discharges. It includes the dispersion of toxic gas cloud in the air after a chemical discharge, and the ability to model some fire and explosion scenarios (Jones et. al., 2013).

At the first stage, the discharge rate is calculated from various scenarios: tanks, pools, gas pipelines, chimneys, etc... The variation of discharge over time is calculated separately. Depending on the type of scenario, the amount of spread and evaporation of the leaking liquid on land or sea is calculated (Jones et. al., 2013).

After the sources of discharge, the type of scenario is determined. Possible Outcome – Scenario types are: Toxic gas cloud spreads, BLEVE (Boiling Liquid Expanding Vapor Explosions), Jet fires, liquid surface fires, vapor cloud explosions (VCE – UVCE) (Jones et. al., 2013).

Each hazard-disaster type is evaluated for its effects according to the scenario type: Toxicity, Flammability, Thermal Radiation and Overpressure. The spread of clouds in the atmosphere is calculated realistically by entering detailed geographical location marking and current actual or regional average meteorological data (Jones et. al., 2013).

ALOHA incorporates various algorithms that are published and accepted in the international literature based on scientific research data. In each scenario, geographical information, scenario-specific information, chemical substance information, meteorological information are evaluated together, and the algorithm selected according to the scenario is run in the background and results of effects are calculated (Jones et. al., 2013).

The methodology for calculation of effects used in the most typical scenarios are (Jones et. al., 2013):

- Liquid discharge: Bernoulli equations (Van den Bosch, 2005)
- Gas discharge: LEAKR (Van den Bosch, 2005)
- Atmospheric dispersion (Neutral Gas): Gaussian (Van den Bosch, 2005)
- Atmospheric dispersion (Dense Gas): DEGADIS (Spicer & Havens, 1987)
- Atmospheric stability (Pasquill, 1961)
- Evaporation (Briscoe & Shaw, 1980)
- Toxicity: EPA AEGL (EPA AEGL website)
- Chemical Properties: DIPPR (U.S. AICHE)

One of the most important features of ALOHA is incorporation of DIPPR database values for chemicals. DIPPR is a database of physico-chemical properties of chemicals and contains many licensed chemical substance data information within its own structure. It is the most widely used property database in the world and is prepared by the Physical Properties Design Institute, a sub-unit of the American Institute of Chemical Engineers AICHE (Jones et. al., 2013).

After each scenario is calculated and modelled with the relevant algorithms, it is first prepared as text output. The type of effect (fire = thermal radiation; explosion = excess pressure; gas cloud = concentration of the chemical) magnitudes and result distances are the most important parameters in the result outputs. The physical impact numerical data is then converted into damage – damage (destruction, health impact, mortality rate, injury rate, machinery damage, etc.) data based on the known damage – damage methodology according to the scenario (e.g. death distance as a result of explosion – permanent health damage within 1 hour as a result of toxicity, 1-2-3rd degree burns within 1 minute as a result of fire). Therefore, as a result, the damage outcomes are connected to the distances in relation to the center of the incident and the impact outcome vs. geographical distance is calculated on a scale of min. 10 m. to a maximum of 10 km (Jones et. al., 2013; Zapert, 1991).

These data can be depicted in a representative graph in ALOHA, or they can be transferred to a geographic information system (GIS) application, to be coordinated on the map and displayed together with other layers such as points of interest (POI) in settlements (i.e. schools, mosques, factories, stops, etc.). GIS software such as Google EARTH, Esri ARCMAP or CAMEO MARPLOT can be used for this purpose.

**2.1. The Scenario: Dispersion in a Forest**

In this study two scenarios are studied with ALOHA software. The chemicals chosen are: Nitrogen Dioxide that represents combustion gases and Ethylene Fluorohydrin that represents pesticides. As forest tree density may differ from site to site, an additional factor (Z = ground roughness) to represent tree density was also considered as a variable in modelling. The outflow rates of all scenarios are taken to be high to be able to differentiate between results to come to meaningful postulations.

For meteorological conditions typical wind patterns and condition from northern Istanbul - Türkiye were selected to be modelled (wind direction: NW / wind speed: 5 m/s / Stability: F (nighttime).

EPA (USA) AEGL and PAC data were used to model toxic effects. Results were categorized to EPA emergency response toxicity levels (AEGL and PAC) with level 1 being the threshold of health risk and level 3 being the risk of death due to exposure. These correspond to different gas concentrations with calculated distances from the event point of origin. All levels are expressed in terms of the concentration of the chemical substance in ppm or mg/m3 at a site where it is estimated that the general population, including susceptible individuals, may live. The detailed levels of AEGL as described by EPA are (EPA AEGL Website):

Level 1 (AEGL-1 / PAC-1)
Noticeable discomfort, irritation or certain asymptomatic non-sensory effects. However, the effects are not permanent health problem posits and are reversible upon termination of exposure.

Level 2 (AEGL-2 / PAC-2)
Irreversible or other serious, long-term adverse health effects or an inhibition of escape.

Level 3 (AEGL-3 / PAC-3)
Life-threatening health effects or death.

## 3. Results and Discussion

The considered events to be modelled are divided into two different scenarios representing two different chemical spills. Each scenario is modelled also with two different ground roughness chosen values and all in total makes 4 different set of modelling runs with AEGL distance outcomes. The scenarios are:

Scenario 1:
Forest Environment with compact tree positioning (Z factor = 2 m.) and loose tree positioning (Z factor = 0.03 m.).
Usage of fuel (Nitrogen Dioxide representing combustion products was modelled).

Scenario 2:
Forest Environment with compact tree positioning (Z factor = 2 m.) and loose tree positioning (Z factor = 1 m.).
Usage of pesticide (Ethylene Fluorohydrin representing pesticides was modelled).

In Scenario 1, when the ground roughness is at 2 meters (representing a dense forest) the contoured concentrations of interest are found to be:
20 ppm (AEGL-3 [60 min]) = 216 meters
12 ppm (AEGL-2 [60 min]) = 283 meters
0.5 ppm (AEGL-1 [60 min]) = 1.5 kilometers

While in the same scenario, when ground roughness is at 0.03 meters (representing a clearing or low shrubberies) the results are:
20 ppm (AEGL-3 [60 min]) = 251 meters
12 ppm (AEGL-2 [60 min]) = 328 meters
0.5 ppm (AEGL-1 [60 min]) = 1.8 kilometers

The results of the models are contoured in Figure 1 and all the results of the scenarios are given in Table 1.

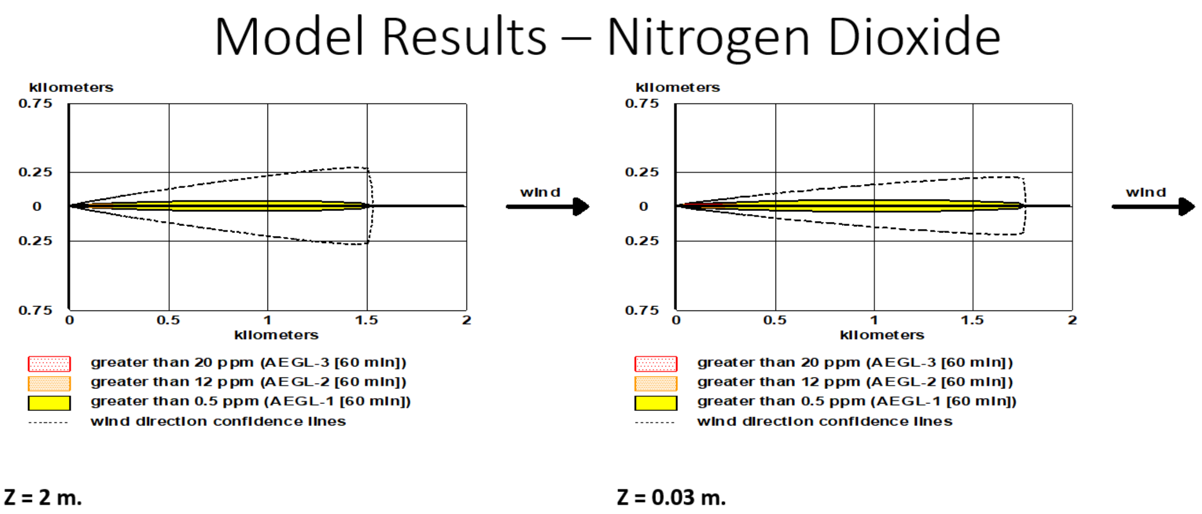



Figure 1. Dispersion modelling results of Scenario 1 contoured according to AEGL concentrations

Table 1. Concentration level results of all scenarios

| **Scenario 1** | | | | | | **Scenario 2** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Z = 2 m.** | | | **Z = 0.03 m.** | | | **Z = 2 m.** | | | **Z = 0.03 m.** | | |
| AEGL3 | AEGL2 | AEGL1 | AEGL3 | AEGL2 | AEGL1 | PAC3 | PAC2 | PAC1 | PAC3 | PAC2 | PAC1 |
| 20 ppm | 12 ppm | 0.5 ppm | 20 ppm | 12 ppm | 0.5 ppm | 0.35 ppm | 0.027 ppm | 0.0025 ppm | 0.35 ppm | 0.027 ppm | 0.0025 ppm |
| 216 m. | 283 m. | 1.5 km. | 251 m. | 328 m. | 1.8 km. | 1.3 km. | 7.1 km. | >10 km. | 2.4 km. | >10 km. | >10 km. |

For Scenario 2, when the ground roughness is at 2 meters (representing a dense forest) the contoured concentrations of interest are found to be:
0.35 ppm (PAC-3 [60 min]) = 1.3 kilometers
0.027 ppm (PAC-2 [60 min]) = 7.1 kilometers
0.0025 ppm (PAC-1 [60 min]) = >10 kilometers

In the same scenario, when ground roughness is at 0.03 meters (representing a clearing or low shrubberies) the results are:
0.35 ppm (PAC-3 [60 min]) = 2.4 kilometers
0.027 ppm (PAC-2 [60 min]) = >10 kilometers
0.0025 ppm (PAC-1 [60 min]) = >10 kilometers

The results of the models are contoured in Figure 2 and all the results of the scenarios are also given in Table 1.

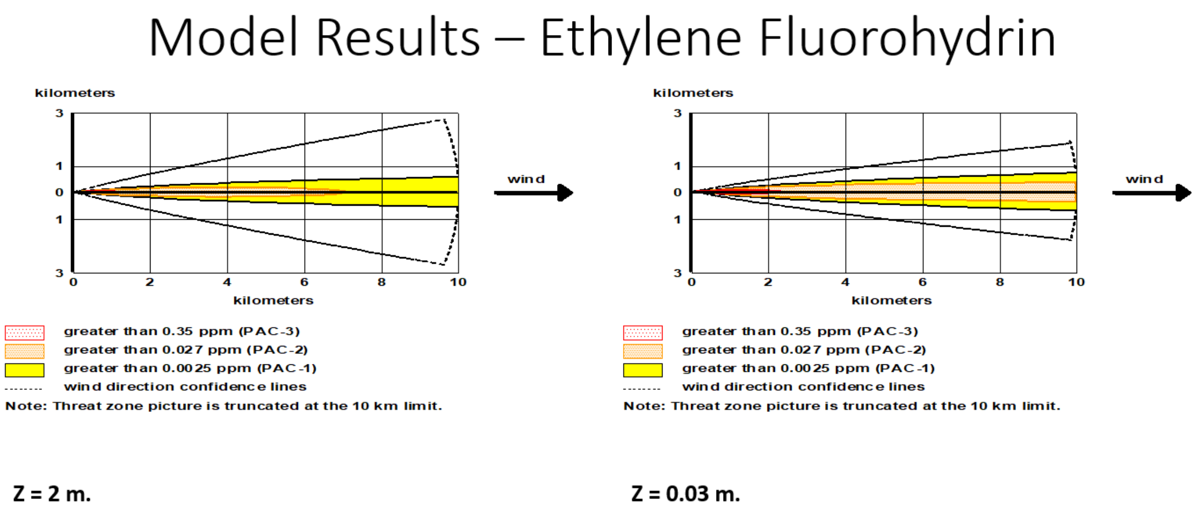



Figure 2. Dispersion modelling results of Scenario 2 contoured according to AEGL concentrations

All these results show clearly that, contrary to popular belief gas clouds can travel easily in forest environments and may pose risk to people working in forests or nearby settlements. This has been found to be true for both Scenario 1 for which a neutral gas was modelled and also for Scenario 2 for which a denser than air gas dispersion was modelled.

Lower frequency of tree positioning in a forest will result in a greater range of spread for gas cloud. The frequency of tree positioning do introduce a factor to control cloud spread and range. But even in dense forests this factor does not make such an event safe in terms of ranges. For dense gas releases the range reduction in a dense forest is found to be able to rise as high as ~30%, however this ratio is found to be lower for neutral gas cloud dispersions. Therefore, it can be postulated that for dense forests, there may be lower ranges for hazards when the event involves a dense gas. But this fact does not make much noticeable change to result in making a lower risk assessment.

Although the results immensely depend on the originating outflow rate (the discharge rate of the spill) and this value was deliberately taken to be high, it is still a possible rate that can be encountered in major spill events (such as tank leakage – pipe breakage). Therefore, the resulting distances in our model runs can indeed be encountered in a major real life accident that would take place in a forest area.

One of the key aspects during risk assessments are therefore the worksites inside forests and also even more so the populated areas nearby the forest area to undergo the accident. As the forest will play a masking – veiling role to conceal the travelling gas cloud in a major accidental scenario, the population's reaction times and therefore capacity to escape will be lower than usual even at daytime conditions.

In Disaster Risk Assessment it is important to use GIS tools as the event proportions may pose a regional risk enveloping even nearby settlements. Studying these scenarios proactively is also important for forest work safety as these chemicals are also used in forestry works. For such major accidental scenarios as mentioned above it is imperative to include GIS based models in the risk assessment studies. An example of such a scenario study is given in Figure 3 (Mannan, 2012).

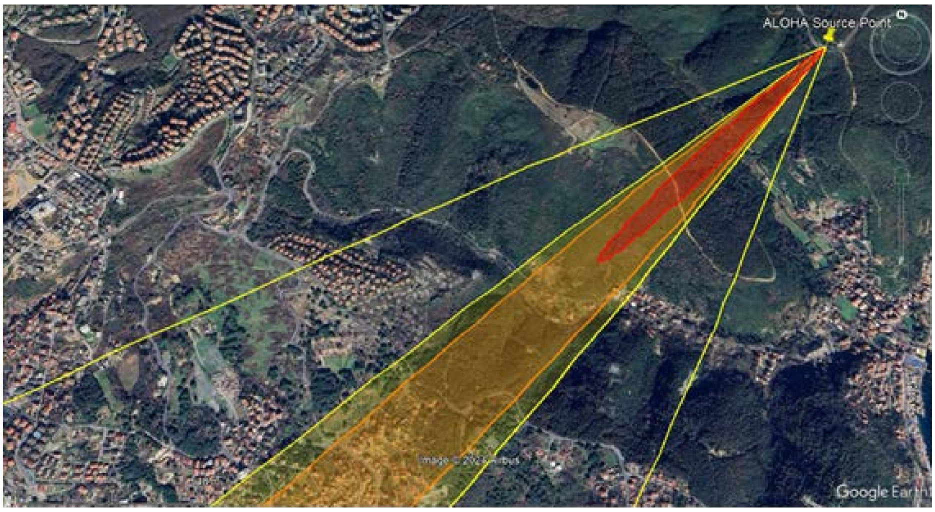



Figure 3. An exemplary showcase of dispersion modelling result contours using a GIS application

## 4. Conclusions

The results show that considering highly toxic chemicals like pesticides used in forest works, studying the effects of potential gas dispersion scenarios beforehand in a risk assessment is paramount in terms Occupational Health and Safety and also Disaster Emergency Planning.

Uncontrolled spills of such chemicals in a forest may lead to an event that may not be able to be responded with local response teams and may require nationwide disaster control.

Therefore, it is imperative to study disaster management scenarios for these events by regional authorities and governmental disaster management agencies.

As the events in forests can pose as great as a risk like a major industrial accident, similar criteria to assess these events should be considered in hazardous sites inside forest areas. In addition to that, to prevent local population and alarm them in case a large spill event occurs, gas detection networks coupled with local alarming systems should be installed in forest areas where hazardous chemicals are used or stored in dangerous amounts (Mannan, 2012).

The assessment works of such events are clearly very multi-disciplined. Expert knowledge of forestry engineering, chemistry, chemical – mechanical engineering, geography, meteorology and atmospheric sciences are required to make these assessments in a realistic manner.

**Acknowledgements**
The authors would like to thank İkram ÇELİK (Istanbul Regional Directorate of Forestry, Department of Forest Firefighting) and Dr. Tolga BARIŞIK for their valuable insights that were considered while devising the scenarios.

**References**
Briscoe F. & Shaw P., (1980). Spread and evaporation of liquid. *Progress in Energy and Combustion Science*, 6/2, 127-140.
Ermak, D., (1990). SLAB: An Atmospheric Dispersion Model for Denser Than Air Releases. Lawrence Livermore Laboratory, 150 pp.
Health and Safety in Forestry Guide, Ministry of Labour, South Africa.
Homberger, E., Reggiani, G., Sambeth, J., Wipf, H. K., (1979). The Seveso Accident: Its Nature, Extent and Consequences.
Jones, R., Lehr, W., Simecek-Beatty, D., Reynolds, R.M., (2013). ALOHA ® (AREAL LOCATIONS OF HAZARDOUS ATMOSPHERES) 5.4.4 TECHNICAL DOCUMENTATION, NOAA Technical Memorandum NOS OR&R 43, 96 pp.
Mannan, S., (2012). Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control, 4th ed. Butterworth-Heinemann.
Pasquill, F., (1961). The Estimation of The Dispersion of Windborne Material. *Met. Mag.*, 90, 33.
Risk Assessment Check List in Log Production Works, Turkish MLSS General Directorate of Occupational Health and Safety, 2016
Spicer T.O. & Havens J.A., (1987). Field Test Validation of the DEGADIS Model. *Journal of Hazardous Materials.* 16, 231-245.
Van den Bosch, C.J.H., Weterings, R.A.P.M. ed., (2005). Methods for the Calculation of Physical Effects CPR14E (Yellow Book). Comimittee for the Prevention of Disasters, 3rd ed., NL.
Zapert, J., (1991). Evaluation of Dense Gas Simulation Models. EPA Report, 114 pp.
Internet References, https://www.epa.gov/aegl/about-acute-exposure-guideline-levels-aegls (Accessed: 09.01.2024)