KSFE FETEC KAFET IUFRO

International Conference of KSFE-FETEC 2025

Innovations in forest engineering to manage forest disasters and enhance the efficient utilization of wood and biomass

PROCEEDINGS

June 30-July 2, 2025
Seoul, South Korea

Seoul National University
Hoam Faculty House, 1 Gwanak-ro, Seoul, South Korea
https://public.thinkonweb.com/sites/ksfe2025

| Conference Sponsor |

Korea Forest Service
National Institute of Forest Science
(사)한국산림기술사협회
YURAH
FORMEC Forest Mechanization

COMMITTEES

Organizational Committee

Assoc. Prof. Dr. Sang-Kyun Han (Chair)
KSFE, Kangwon National University, Chuncheon, South Korea

Prof. Dr. Mehmet Eker (Co-Chair)
FETEC, Isparta University of Applied Sciences, Isparta, Türkiye

Prof. Dr. Jungil Seo (Co-Chair)
KSFE, Kongju National University, Yesan, South Korea

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

Dr. Jae-Heun Oh
KSFE, National Institute of Forest Science, Pocheon, South Korea

Prof. Dr. Han-Sup Han
Northern Arizona University, Flagstaff, United States of America

Conference Sponsor

Korea Forest Service

National Institute of Forest Science

KFPEA (사)한국산림기술사협회 Korea Forest Professional Engineer Association

YURAH

FORMEC Forest Mechanization

Scientific Committee

Abdullah E. Akay (SC Chair), BTU, Bursa, Türkiye
Ebru Bilici, GU, Giresun, Türkiye
Mehmet Eker, IUAS, Isparta, Türkiye
Selçuk Gümüş, KTU, Trabzon, Türkiye
Tolga Öztürk, IUC, İstanbul, Türkiye

Dzhamal Amishev, LU, Canada
Kazuhiro Aruga, UDAI, Japan
Stelian Alexandru Borz, UNITBV, Romania
Norizah Kamarudin, UPM, Malaysia
Raffaele Spinelli, IBE-CNR, Italy

Dongyeob Kim, (DU), Daegu, South Korea
Teaho Bong, University (CBNU), Cheongju, South Korea
Eenjai Lee, (YU), Gyeongsan, South Korea
Seonghun Jeong, (GNU), Jinju, South Korea
Hyeongkeun Kweon, (KNUAF), Jeonju, South Korea
Wonseok Kang (MNU), Muan, South Korea

INTRODUCTION

Forest disasters such as landslides and wildland fires are key issues in today's forest management, especially for forestlands on steep slopes with a limited access. A major event of forest disasters can significantly disrupt an ongoing effort of sustainable forestry and leave unrecoverable damages to rural communities. Up-to-date forest engineering technologies and operational practices have been increasingly adopted to minimize the risk of forest disasters while supporting active forest management practices.

The use of forest engineering technologies for various forest management activities for which timber production is not a primary objective is now common today's forestry, as we often deal with man-made high-density stands and non-traditional operations to accomplish various forest management objectives. Also, it should be noted that environmental issues such as soil impacts and water quality are ongoing challenges that need to be addressed for both successful industrial and non-industrial timber operations. Recent innovations in artificial intelligence and precision forestry can be effectively used to improve operational efficiency while minimizing safety and environmental risks.

In 30 July-2 August, over 100 participants from different countries gathered in Seoul, S. Korea, for the **International Conference of KSFE-FETEC 2025** organized by Korean Society of Forest Engineering (KSFE). The meeting, which involved IUFRO RG 3.01.00, was kindly hosted by the Seoul National University. The co-organizers include Forest Engineering and Technologies Platform (FETEC) and Korea Association of Forest Enviro-conservation Technology (KAFET).

At the conference, the most recent scientific and professional research works in forest operations and engineering, focusing on managing forest health, forest fires, landslides, and biomass utilization was discussed in 10 technical sessions by international researchers, practitioners, and relevant shareholders from all over the world. In the 3rd day, a technical field trip was conducted in Gwangneung Experimental Forest of Forest Technology and Management Research Center in Pocheon. Technical information given about reforestation, forest management, and forest roads in South Korea. Also, active timber harvesting operations were demonstrated in an excursion session.

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.

Prof.Dr. Sang-Kyun Han
(Chair)
Kangwon National University
Chuncheon, South Korea

TABLE OF CONTENTS

page

.

Measuring Tree Diameter Using a Lidar-Enabled Smartphone Application

Abdullah E. Akay

Forest Engineering Department, Faculty of Forestry, Bursa Technical University, 16310 Bursa, Türkiye
abdullah.akay@btu.edu.tr

Abstract

In recent years, smartphones with LiDAR sensors have begun to be used as an economical, fast and effective alternative for tree diameter measurement. In this study, the capabilities of a LiDAR-enabled smartphone were tested in measuring tree diameters of Stone pine (*Pinus pinea*) and Cypress trees (*Cupressus sempervirens*) located in Bursa Technical University campus in Bursa, Türkiye. iForester, a user-friendly and AI-assisted application, was used for breast height diameter (DBH) of sample trees. In the study, the performance of the smartphone application was evaluated with the classical measurement method carried out using a caliper. The accuracy of the LiDAR-enabled smartphone application was investigated based on Mean Square Error (MSE) and Root Mean Square Error (RMSE) methods. The results showed that the smartphone method provided good accuracy for both tree species. MSE values for Stone pine and Cypress were determined as 3.89 and 0.99, respectively, when using DBH measurement mode. RMSE values of the species were determined as 1.97 and 0.99, respectively. When the tree species were compared, the tree diameter was determined with higher accuracy in the sample area with cypress trees, due to relatively more cylindrical and smooth stem formation.

Keywords: *Stand parameters, tree diameter, smartphone, iForester*

1. INTRODUCTION

Forests exist in certain habitats, their main elements are trees and shrubs, as well as other plant, animal and mineral elements. In addition, forests are a national asset that provides forest products, other functions and services to society. Forests, which are among the most important natural resources, need to be managed and operated with a precision forestry approach in order to ensure the sustainability of the products, services and services they offer. The precision forestry approach aims to provide optimum efficiency from forest resources and to minimize environmental damage by using modern techniques and technological tools in order to make economic, environmental and sustainable decisions in forestry studies (Kovácsová and Antalová, 2010).

In the production of wood raw materials, it is necessary to use modern and technological methods by taking into account the precision forestry approach. In Türkiye, the production of wood based forest products is carried out by the State Forest Enterprises in order to meet the needs of the markets. Wood production activities consist of the stages of cutting and felling, delimbing, debarking, bucking, extracting from the harvesting unit, loading, haulig, unloading and stacking (Eker and Acar, 2006). The first stage of production works in the forest is the marking of the trees decided to be cut according to the plan (Yıldırım, 1989). This marking process is done with a stamp and is carried out within the principles specified in the Stamp Regulation (Anonymous, 2004).

These stamps, called planted tree stamps, should be applied to the trees to be cut within the harvesting plan, in a way that it will remain on the stump after the tree is cut. The stamp is applied to trees with a breast height diameter (DBH) of 20 cm and above (Anonymous, 2004). The planted stamp team that carries out the stamping works includes the forest engineer, forest ranger, compassman, axeman, recorder and stamper. The materials that should be in this team consist of the management plan and silviculture application plan of the place where the stamp will be made, maps, planted tree stamp, planted tree measurement report, paint and writing brush or numerator, caliper, inclinometer (clisimeter), tape measure, altimeter, binoculars and axe.

The diameter (DBH) measurement is made from the uphill side of the selected tree at breast height (1.30 meters) and with a caliper according to the slope of the tree. Measuring from the downhill side may cause errors. Breast height level can be determined by measuring with a tape measure, but this takes a significant amount of time. On the other hand, determining the 1.30-meter breast level of the diameter gauge on the caliper before starting the stamping job provides a practical measurement opportunity (Menemencioğlu et al., 2013). However, this measurement method may not give accurate results as expected. In addition, difficult terrain conditions and dense vegetation make the diameter measurement stage difficult in stamping jobs.

In recent years, smartphones with LiDAR sensors have begun to be used as an economical, fast and effective alternative for tree diameter measurement. Mobile applications developed specifically for tree diameter measurement and installed on smartphones provide significant technological advantages in diameter measurements. In this paper, the iForest application running on the iPhone 12 ProMax smartphone was used to determine the breast height diameter of Stone Pine (*Pinus pinea*) and Cypress trees (*Cupressus sempervirens*) located at the Bursa Technical University Mimar Sinan campus. In order to investigate the accuracy of the diameter values obtained, the diameters of sample trees were also measured with the classical caliper method and the results were compared.

2. MATERIAL AND METHODS

2.1. Study Area

The study was carried out in an area where Stone Pine (*Pinus pinea*) and Cypress trees (*Cupressus sempervirens*) were located near Bursa Technical University Mimar Sinan Campus. Diameter measurements were made on a total of 60 trees, 30 from each species, in the study area (Figure 1).

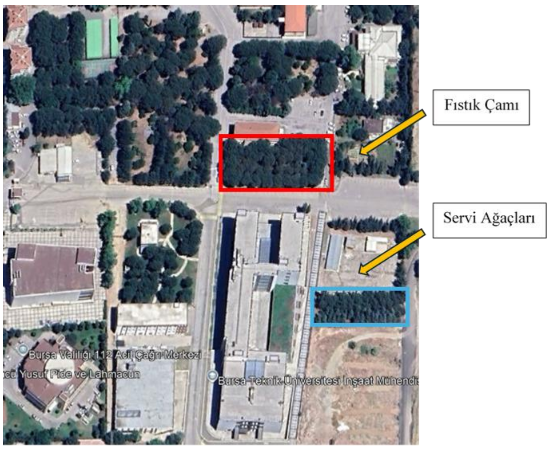


Figure 1. Study area

In the classical measurement of tree diameters, a Haglöf model caliper was used. In LiDAR sensor measurements, an iPhone 12 ProMax smartphone and the iForest application were utilized (Figure 2).

(a) (b)

Figure 2. Instruments used in the field: a) iPhone 12 ProMax phone, b) Haglöf model caliper

2.2. Method

The method section consists of two stages; 1) diameter measurements and 2) statistical analysis and accuracy analysis.

2.2.1. Diameter measurements

In this study, the breast height diameters of 30 sample trees selected from two sample areas were measured using the classical method using a caliper and a smartphone with a LiDAR sensor (Figure 3 and Figure 4). The iForester application was used during the measurements. iForester is an integrated artificial intelligence-supported smartphone application that automatically calculates the breast height diameter for each tree with minimal user input, such as touching the photographic image of the tree base on the screen (Perseus, 2024) (Figure 5). iForester calculates the breast height location when the tree base is touched on the screen and can automatically calculate the diameter (DBH) of this point. In addition, the application can perform manual diameter measurement (Other) for any point determined on the trunk on the phone screen. In the diameter measurement performed using a smartphone, both methods available in the application (automatic and manual) were used. The tree diameter data collected in the field were recorded in data recording forms. The sample trees were numbered and the measurements for each tree were recorded in the MsExcel page.

Figure 3. Diameter measurement with caliper within the scope of the classical method

Figure 4. Diameter measurement with LiDAR equipped smartphone

Figure 5. Diameter measurement using iForester application

2.2.2. Statistical Analyses and Accuracy Analysis

The relationships between tree diameters determined with calipers and smartphones in sample areas were examined with statistical analyses. SPSS 20 and MsExcel programs were used for statistical analyses. R^2 value was calculated to analyze the accuracy of linear relationships in the analyses. Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) were calculated to examine the measurement error between stand parameters measured in the field and determined with smartphone data (Equations 3.1-3.2). In these calculations, N represents the number of sample trees, yi represents field measurements and ŷi represents the values determined with smartphone data.

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_{i)})^2 \qquad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_{i)})^2} \qquad (2)$$

3. RESULTS AND DISCUSSION

3.1. Diameter Measurement Findings

Stand parameters of sample trees are presented in Table 1 and Table 2. In the stone pine area, average tree diameters were determined as 40.52 m, 40.50 cm and 40.40 cm for caliper, automatic and manual measurements, respectively. In the cypress area, average tree diameters were determined as 29.27 m, 29.51 cm and 29.32 cm for caliper, automatic and manual measurements, respectively. Descriptive statistical findings regarding stand parameters are given in Table 3 and Table 4.

In the stone pine area, it was determined that there was a high level of linear relationship (R^2) between the tree diameter values determined with a caliper in ground measurements and the values determined with a LiDAR-equipped smartphone (Automatic: 0.95 and Manual: 0.98) (Figure 6 and Figure 7).

In the cypress tree area, it was determined that there was a high level of linear relationship (R^2) between the tree diameter values determined with a caliper in ground measurements and the values detected with a LiDAR-equipped smartphone (Automatic: 0.98 and Manual: 0.99) (Figure 8 and Figure 9).

Table 1. Tree diameter values obtained by ground measurements in the stone pine area (cm)

Tree No	Caliper	Automatic	Manual	Tree No	Caliper	Automatic	Manual
1	44.20	44.20	42.67	16	47.50	48.01	46.74
2	39.70	42.93	43.18	17	36.20	36.07	36.07
3	42.00	40.89	40.64	18	34.60	31.50	33.27
4	51.20	51.31	52.07	19	34.80	35.81	33.78
5	42.00	41.40	41.66	20	46.50	46.48	45.47
6	30.60	26.92	28.45	21	40.20	42.16	40.89
7	35.70	37.08	36.07	22	31.60	30.23	31.24
8	38.00	42.16	41.40	23	33.10	33.27	33.02
9	43.00	41.40	41.91	24	23.30	25.91	23.62
10	36.70	36.58	35.81	25	44.20	45.47	42.93
11	32.10	29.72	32.00	26	50.80	49.28	52.58
12	40.10	42.42	41.40	27	49.50	49.78	50.04
13	37.60	36.32	35.81	28	48.30	47.50	49.53
14	33.50	32.51	32.51	29	61.30	56.90	60.45
15	29.80	30.48	29.72	30	57.40	60.20	57.15

Table 1. Tree diameter values obtained by ground measurements in the cypress area (cm)

Tree No	Caliper	Automatic	Manual	Tree No	Caliper	Automatic	Manual
1	26.80	25.20	26.90	16	27.20	28.20	27.90
2	21.20	23.90	21.50	17	21.00	20.60	20.30
3	22.50	23.60	22.80	18	34.00	33.50	34.50
4	21.80	22.10	22.30	19	45.00	45.00	44.20
5	22.50	22.40	22.30	20	44.80	44.00	44.00
6	32.20	33.00	32.70	21	28.00	27.20	28.00
7	30.40	31.50	30.00	22	20.70	20.20	20.30
8	26.50	27.10	26.40	23	22.00	23.60	20.40
9	37.00	37.80	37.80	24	38.70	38.80	38.10
10	40.20	41.60	40.30	25	37.00	36.60	37.50
11	27.00	27.90	27.10	26	24.70	24.60	25.40
12	28.30	27.20	28.20	27	24.60	25.40	25.30
13	33.00	32.00	33.50	28	20.90	21.00	21.50
14	30.50	30.50	30.20	29	28.10	29.30	28.90
15	36.60	37.80	37.00	30	24.80	23.60	24.40

Table 3. Descriptive statistics for tree diameter (cm) values for stone pine

	N	Ortalama	Minimum	Maksimum	Standard Sapma
Caliper	30	40.52	23.30	61.30	8.52
Automatic	30	40.50	25.91	60.20	8.58
Manual	30	40.40	23.62	60.45	8.75

Table 4. Descriptive statistics for tree diameter (cm) values for cypress

	N	Ortalama	Minimum	Maksimum	Standard Sapma
Caliper	30	29.27	20.70	45.00	7.16
Automatic	30	29.51	20.20	45.00	7.12
Manual	30	29.32	20.30	44.20	7.13

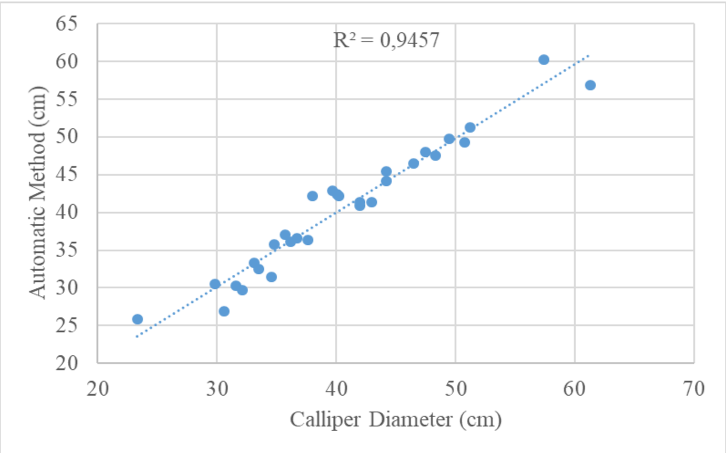


Figure 6. Linear relationship between stone pine diameters measured by caliper and automatic method

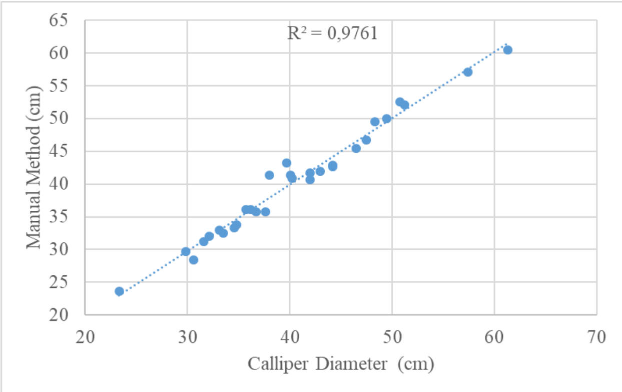


Figure 7. Linear relationship between stone pine diameters measured by caliper and manual method

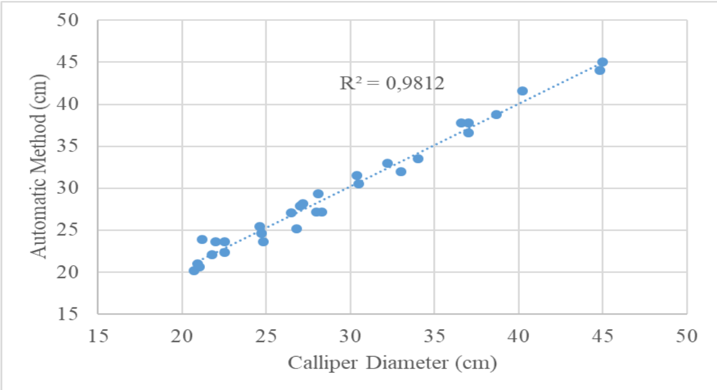


Figure 8. Linear relationship between cypress diameters measured by caliper and automatic method

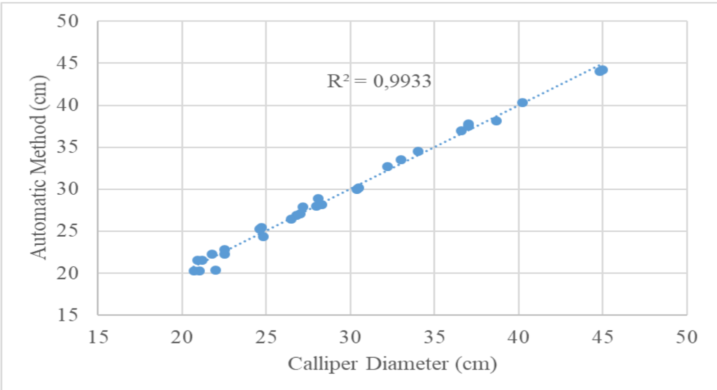


Figure 9. Linear relationship between cypress diameters measured by caliper and manual method

3.2. Accuracy Assessment Findings

The measurement error between tree diameters obtained using traditional calipers and those measured with a LiDAR-equipped smartphone was evaluated using Mean Squared Error (MSE) and Root Mean Squared Error (RMSE). The results showed that smartphone-derived diameter values had acceptable accuracy compared to traditional caliper measurements in both study areas (Table 5).

When comparing the automatic and manual methods for determining tree diameter, the manually measured diameters were found to be more accurate. The primary reason for this is that, in the manual method, the smartphone-measured diameter is taken at the same point as the caliper measurement. In contrast, the automatic method (using iForester) marks the tree's base point and then automatically determines breast height (1.3 m) to measure the diameter. However, obstacles such as ground vegetation or exposed root structures can sometimes interfere with the correct identification of breast height, leading to measurement errors.

When comparing tree species, the error was lower for cypress trees than for pine trees. This is mainly because cypress trees have a more cylindrical and uniform trunk structure compared to the sampled pine trees, allowing the iForester application to produce more accurate diameter estimates under these conditions.

Table 5. Measurement error between caliper measurements and diameters determined by smartphone

Method	Stone pine trees		Cypress trees	
	MSE	RMSE	MSE	RMSE
Automatic	3.89	1.97	0.998	0.994
Manual	1.80	1.34	0.335	0.579

3. CONCLUSION AND SUGGESTIONS

This study evaluated the effectiveness of LiDAR-equipped smartphones in measuring tree diameters, utilizing the AI-powered, user-friendly, and efficient iForester application. Field tests were conducted in two sample areas consisting of pine and cypress trees. The accuracy of smartphone-based measurements was compared against traditional caliper measurements, with performance assessed using Mean Squared Error (MSE) and Root Mean Squared Error (RMSE). The results demonstrated that the smartphone LiDAR method provided highly accurate measurements in both study areas.

For automated measurement methods, the Mean Squared Error (MSE) values were determined as 3.89 for pine and 0.99 for cypress, while the corresponding Root Mean Squared Error (RMSE) values were 1.97 and 0.99, respectively. Comparative analysis revealed significantly higher measurement accuracy for cypress trees in the study area. The analysis revealed that cypress trees, with their smoother and more cylindrical trunks, yielded higher measurement accuracy compared to pine trees. Additionally, manual measurements (where the user precisely selects the measurement point) consistently outperformed automatic methods, particularly in pine trees where trunk irregularities and ground vegetation could affect iForester's breast height detection.

The evaluation of both measurement techniques demonstrates that LiDAR-equipped smartphones present an effective alternative for diameter at breast height (DBH) estimation. Smartphone-based measurements offer significant time savings (estimated 40-60% reduction in measurement duration), reduce equipment requirements and lower operational costs by eliminating specialized tools. Besides, this method enables rapid data collection in field conditions, facilitates larger sample sizes within equivalent timeframes, and minimizes required technical training for field personnel.

REFERENCES

Akay, A.E., Sessions, J., Aruga, K. 2007. Designing a forwarder operation considering tolerable soil disturbance and minimum total cost, Journal of Terramechanics. 44(2): 187-195.

Anonim (2004). Damga Yönetmeliği. Orman ve Su İşleri Bakanlığı, 10.04.2004 tarih ve 25429 sayılı Resmi Gazete, Ankara.

Eker, M., Acar, H.H. 2006. Development of Annual Operational Planning Model for Timber Harvesting. Süleyman Demirel University Journal of the Institute of Science, 10(2): 235-248.

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 Sens., 10(11): 1845.

Gülci, S., Yurtseven, H., Akay, A. O., Akgül, M. 2023. Measuring tree diameter using a LiDAR-equipped smartphone: a comparison of smartphoneand caliper-based DBH. Environ Monit Assess, 195:678.

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

Menemencioğlu, K., Kılıç, A., Buğday, E. 2013. Ormancilikta dikili ağaç damga işlerinde zaman etüdü. Balıkesir Üniversitesi Endüstri Mühendisliği Bölümü & Türk Ergonomi Derneği, 399-407.

Özdemir, İ. 2013. Determination of individual tree characteristics with terrestrial laser scanning, Süleyman Demirel University faculty of Forestry Journal, 14: 40-47, Isparta.

Perseus, 2024. Promoting Economic Resilience and Sustainability Of The Eastern U.S. Forests. Year 1 Annual Report & Year 2 Work Plan. 13 p.

Tatsumi, S., Yamaguchi, K., Furuya, N. 2022. ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad, Methods in Ecology and Evolution, 14(7): 1603-1609.

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, 43(1): 185–197.

Vatandaşlar, C., Zeybek, M. 2021. Extraction of forest inventory parameters using handheld mobile laser scanning: A case study from Trabzon, Turkey. Measurement, 177: 109328.

Vatandaşlar, C., Zeybek, M., Borucu, S. 2022. The Effect of Sampling Design on Data Precision and Practicality in Mobile-LiDAR-based Forest Inventories: Case Study from Rize Senyuva, Journal of Bartin Faculty of Forestry, 24(2): 258-271.

Yıldırım, M. 1989. İş Etüdü ve Planlaması. İstanbul Üniversitesi Orman Fakültesi Yayınları, İ.Ü. Yayın no:3556, O.F. Yayın No: 402, İstanbul.

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.

Evaluating System Productivity of Multiple Forestry Machines Used in Combination for Sequential Production Systems

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

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

Abstract

Today, most forest harvesting operations rely on modern forestry machinery. The efficiency of these operations depends on the performance of the machines and how they are used in combination with each other, as well as on various site characteristics. In Japan, forest harvesting typically involves the use of multiple machines. The most common system for steep terrain consists of four steps: felling, yarding, processing, and forwarding. These steps require a chainsaw, swing yarder, processor, and forwarder, respectively. This study evaluated the overall productivity of this forest harvesting system using the combined machine productivity (CMP) index through system dynamics simulation. The focus was on how system productivity varies when the speed of each production process changes. The results showed that adding a chainsaw worker could improve overall productivity. Additionally, replacing swing yarders with more powerful tower yarders and increasing the travel speed or maximum load of forwarders was found to be necessary to improve the productivity of Japanese forest harvesting systems in steep terrain, since the production rates of the yarding and forwarding processes, which depend on extraction distance, are potential bottlenecks in these systems.

Keywords: *System productivity, multiple forestry machines, steep terrain, system dynamics, simulation*

1. INTRODUCTION

Productivity, defined as the rate of product output per unit of time for a given production Today, most forest harvesting operations are performed with modern forestry machines, and their efficiency depends not only on the performance of each forestry machine but also on how they are used in combination and on various site characteristics (Yoshimura *et al.*, 2023). In Japan, forest harvesting usually requires multiple forestry machines, and the most common system for harvesting forests on steep terrain involves four stages: felling, yarding, processing, and forwarding. The felling stage uses a chainsaw, the yarding stage uses a swing yarder, the processing stage uses a processor, and the forwarding stage uses a forwarder (Figure 1). This type of forestry operation system, which combines multiple machines, is complex and consequently not very productive. In fact, the productivity of the Japanese forestry industry is significantly lower than that of Central Europe, despite their similar topography. This study aims to evaluate the system productivity of such forest harvesting systems in Japan and to find ways to improve it. In our previous study (Yoshimura *et al.*, 2025), we used system dynamics simulations to calculate combined machine productivity (CMP) to evaluate forest operations that combine multiple machines. This study, on the other hand, focused on how system productivity varies when the speed of each production process changes.

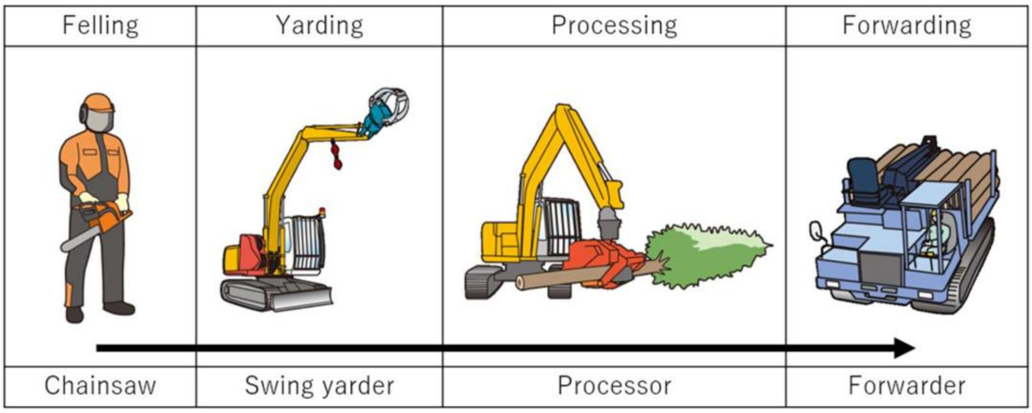


Figure 1. Typical forest harvesting system in Japan

2. MATERIALS AND METHODS

There are three types of forest production systems: serial, parallel, and sequential. In the serial production system, the production processes run in sequence. As shown in Figure 2, Process 2 starts after Process 1 is completed. The total production time of this production system (T_{serial}) is expressed as follows:

$$T_{serial} = T_1 + T_2 \tag{1}$$

where T_1 and T_2 represent the process times for Processes 1 and 2, respectively.

It should be noted that the storage capacity in each production process must equal or exceed the total volume of processed logs. Otherwise, the serial production system will not function, and a parallel or sequential production system must be selected instead (Yoshimura *et al.*, 2025).

In the parallel production system (Figure 3), all production processes run in parallel. It should be noted that the system productivity of the parallel production system is equal to the productivity of the rate-limiting or slowest process (Yoshimura *et al.*, 2025).

The total production time of the parallel production system ($T_{parallel}$) is expressed as follows:

$$T_{parallel} = T_1 \ (T_1 > T_2) \tag{2}$$
$$T_{parallel} = T_2 \ (T_2 > T_1) \tag{3}$$

where T_1 and T_2 represent the process times for Processes 1 and 2, respectively.

The sequential production system falls between the serial and parallel production systems. As illustrated in Figure 4, Process 2 starts when the storage capacity in Process 1 is full. This production system is a viable option when storage capacity is limited in each production process, and the serial production system cannot be chosen (Yoshimura *et al.*, 2025).

The total production time of this production system ($T_{sequential}$) is expressed as follows:

$$T_{sequential} = a(T_1 + T_2) \quad (0.5 < a < 1) \tag{4}$$

where T_1 and T_2 represent the process times for Processes 1 and 2, respectively.

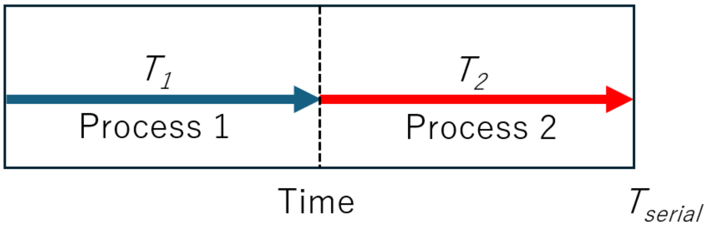


Figure 2. Illustration of the serial production system

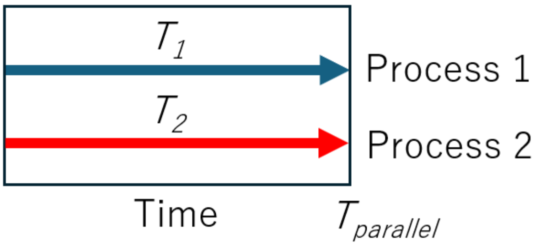


Figure 3. Illustration of the parallel production system

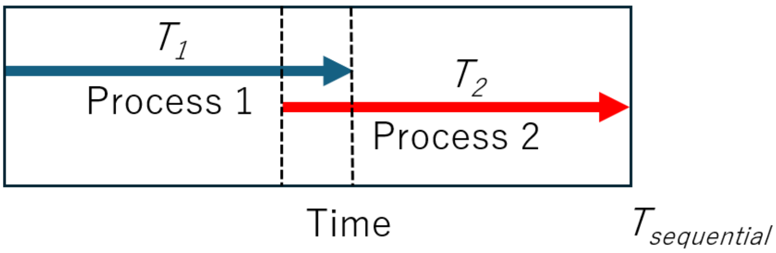


Figure 4. Illustration of the sequential production system

Figure 5 illustrates a system dynamics model of the sequential production system in Japan. It was constructed using Stella Architect software, version 3.7.3 (isee systems). This software is a visual diagram-based simulation tool that helps us understand the behavior of complex systems over time. The simulation conditions in Table 1 are close to the averages of Japanaese forestry, and the total processed log volume is set to 300 m^3. Since the felling process has a storage capacity of 300 m^3, felled trees are left in the forest until the yarding process starts.

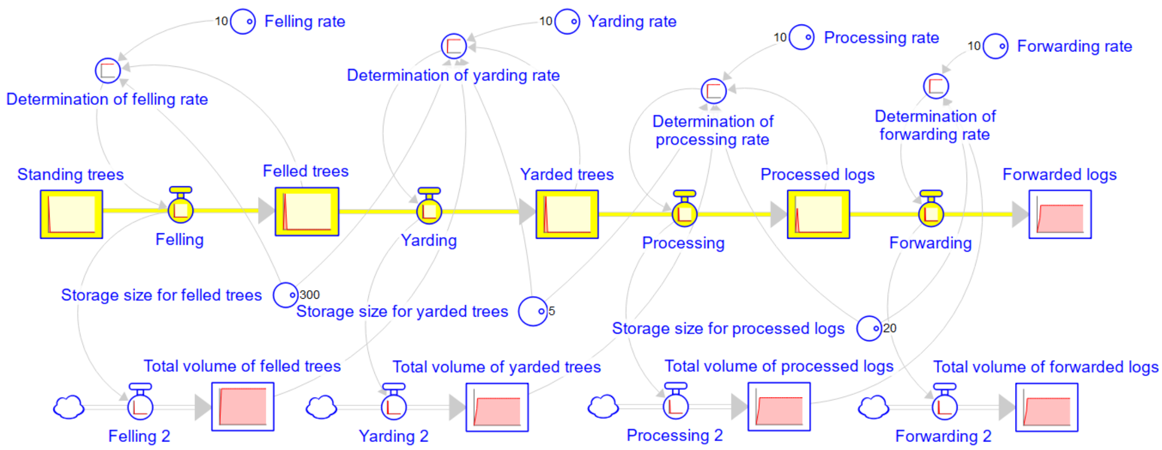


Figure 5. A system dynamics model of the sequential production system in Japan

Table 1. Simulation conditions

Production process	Felling	Yarding	Processing	Forwarding
Production rate (m^3/h)	4	3	7	6
Storage size (m^3)	300	5	20	N/A

3. RESULTS AND DISCUSSION

Figure 6 shows the variation of the overall production rate when the production rate of the felling process varies. It should be noted that the overall production rate is 1.7 m^3/hour under the simulation conditions in Table 1, and this value can be the average of Japanese forestry. The overall production rate can be improved by increasing the production rate of the felling process, and it can reach 2.2 m^3/hour by adding one more chainsaw operator.

Figure 7 illustrates how the overall production rate changes when the yarding process production rate changes. Increasing the yarding process production rate from 3 to 6 m^3/hour was found to increase the overall production rate from 1.7 to 2.2 m^3/hour. The production rate of the yarding process depends on extraction distance and is often the largest bottleneck in Japanese forest harvesting systems. Therefore, replacing swing yarders with more powerful tower yarders is necessary.

Figure 8 shows the variation of the overall production rate when the production rate of the processing process varies. According to this figure, the production rate of the processing process does not significantly impact the overall production rate because it is already limited by the slower processes of felling and yarding that precede processing.

Similarly, Figure 9 shows that the production rate of the forwarding process does not significantly impact the overall production rate because it is already limited by the slower processes of felling and yarding that precede processing. However, it should be noted that the production rate of the forwarding process is significantly affected by extraction distance as well as that of the yarding process, and the forwarding process can often be another bottleneck in Japanese forest harvesting systems.

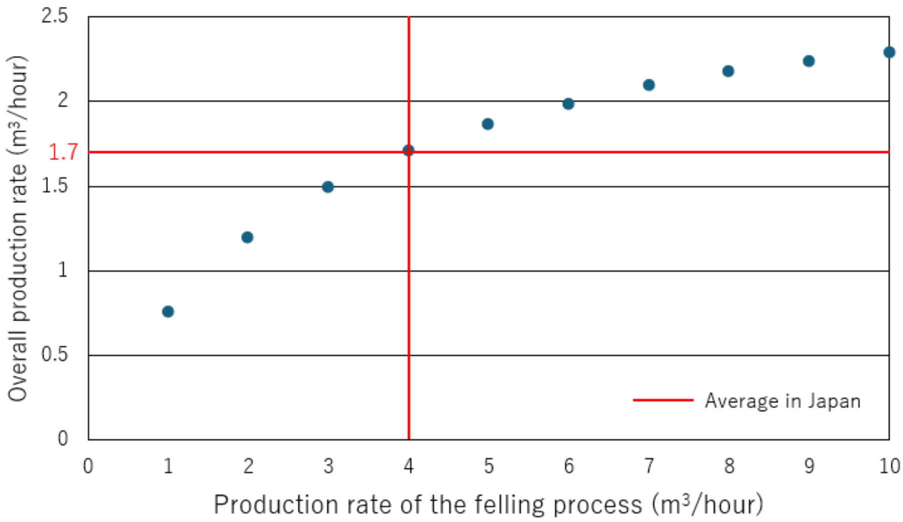


Figure 6. Variation of the overall production rate when the production rate of the felling process varies.

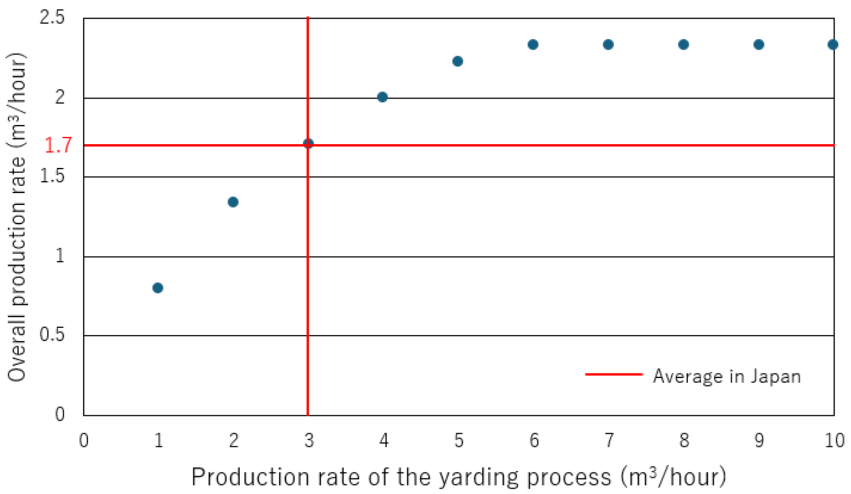


Figure 7. Variation of the overall production rate when the production rate of the yarding process varies

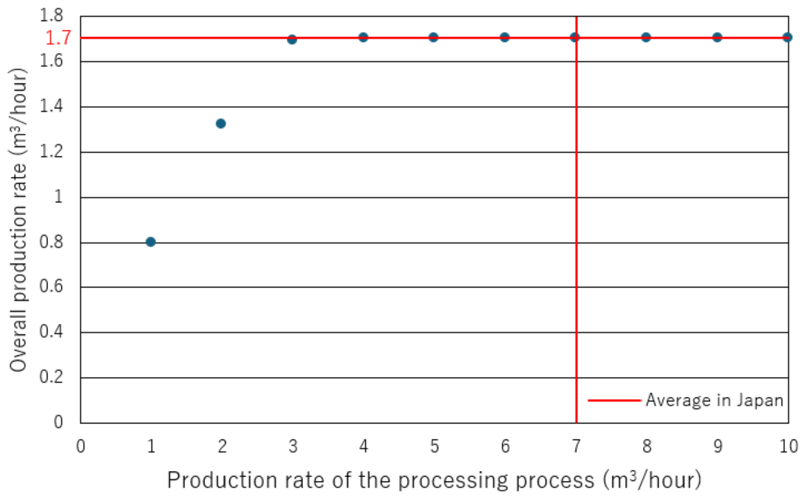


Figure 8. Variation of the overall production rate when the production rate of the processing process varies

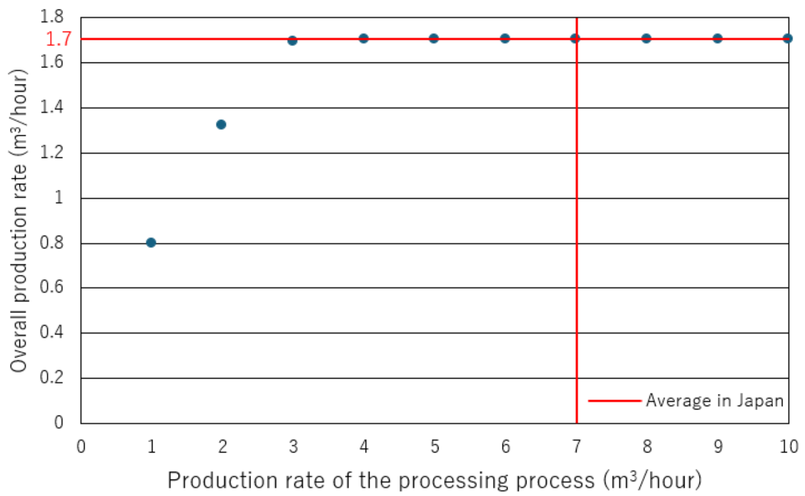


Figure 9. Variation of the overall production rate when the production rate of the forwarding process varies

4. CONCLUSIONS

This study demonstrated ways to increase the productivity of Japanese forest harvesting systems. However, these systems remain much less productive than those in Central Europe. Productivity could be improved by simplifying the production systems or by using a processor tower yarder (PTY), a machine that is commonly used in Central Europe.

REFERENCES

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.

Yoshimura, T., Suzuki, Y., Sato, N. 2025. Application of System Dynamics Simulation to Assess System Productivity of Forest Harvesting Systems: A Case Study from Japan. Forests. 16: 734.

Investigation of Particulate Matter Exposure on Cabinless Agricultural Tractors Used in Forestry Operations

İnanç Taş[1*], Abdullah E. Akay[1], Barış Balcı[1], Halit Büyüksakallı[2]

[1]Forest Engineering Department, Faculty of Forestry, Bursa Technical University, 16310 Bursa, Türkiye
[2]Muğla Sıtkı Koçman University, Köyceğiz Vocational School, 48000 Muğla, Türkiye
*inanc.tas@btu.edu.tr

Abstract

Particulate matter (PM) consists of solid particles suspended in the air, which can have significant health effects depending on their sizes. Particles smaller than 10 microns (PM10 and PM2.5) can penetrate deep into the respiratory tract and reach the lungs, causing serious health risks. In this study, the PM2.5 exposure levels of operators working with cabinless tractors commonly used in forestry were evaluated. In field studies conducted in the Osmangazi Forest Management Chief, measurements were taken on a New Holland TT55B model tractor using two different devices. The average PM2.5 concentration measured with an industrial device (PCE-PCO-2 Particle Meter) was 206.22 µg/m³, while the value recorded with the TriSensor 4.0 multi-measurement device (Arduino based) was 188.94 µg/m³. Similarly, in the Dağtekke Forest Management Chief area, PM2.5 measurements were conducted on a Türk-FIAT 80-66 model tractor. The average PM2.5 concentration was found to be 114.98 µg/m³ with the industrial device and 165.35 µg/m³ with the TriSensor 4.0 device. These results indicate that operators working with cabinless tractors are exposed to high levels of particulate matter, which poses a serious occupational health risk. The study emphasizes the need for preventive measures to improve occupational health and safety in forestry operations.

Keywords: *Agricultural tractors, cabinless work environment, occupational health, particulate matter, PM2.5*

1. INTRODUCTION

Forestry is an important sector encompassing a wide range of working methods, from basic manual techniques to advanced technologies. Initially, production relied heavily on human labor, but over time, technology-driven methods have become more prevalent. The increasing complexity of modern forestry practices has made the occurrence of accidents or hazardous situations—stemming from either human or machine factors—almost inevitable. For instance, the simultaneous use of manual labor and machinery during production can lead to work-related accidents, injuries, occupational illnesses, and labor inefficiencies (Kaakkurivaara et al., 2022). Furthermore, professionals and operators working with machinery are also exposed to machine-related hazards. Today, agricultural tractors are among the most commonly used machines in forestry. Despite their operational benefits, agricultural tractors also pose several risks, among which the generation of particulate matter is particularly significant.

Particulate matter (PM) refers to tiny solid particles that remain suspended in the air and gradually settle due to gravity. Larger, denser particles tend to settle quickly, whereas lighter particles can stay airborne for longer periods. Particles ranging in size from 0.5 to 10 microns can enter the human body through the respiratory system. The health impact of these particles is largely size-dependent. Typically, particles smaller than 10 microns—classified as PM10 (coarse) and PM2.5 (fine)—are considered most hazardous (Taş and Akay, 2019). Particles exceeding 10 microns are generally trapped in the upper respiratory tract, while smaller ones such as PM10 and PM2.5 can penetrate deeper, reaching the alveoli. PM10 particles tend to accumulate in the bronchi, PM2.5 in the alveolar regions, and ultrafine particles around 0.1 microns in diameter can even enter the bloodstream through capillaries. These particles are associated with various health problems, including reduced lung function, asthma attacks, respiratory irritation, shortness of breath, heart attacks, and premature death in individuals with cardiovascular or respiratory conditions (Contini and Costabile, 2024).

Particulate matter is thus a critical issue in forestry operations. It frequently emerges during production activities, particularly when agricultural tractors are in use. This study focuses on the particulate matter generated by agricultural tractors operations and evaluates its potential impact on machine operators.

2. MATERIAL AND METHODS

2.1. Study Area

This study was carried out in Osmangazi and Dağtekke Forest Enterprise Chiefs (FEC) (Figure 1). There are Turkish Red Pine (*Pinus brutia*) trees in the study areas. Measurements were made during the skidding of logs. Only Particulate Matter 10 (PM10) was considered in the measurements.

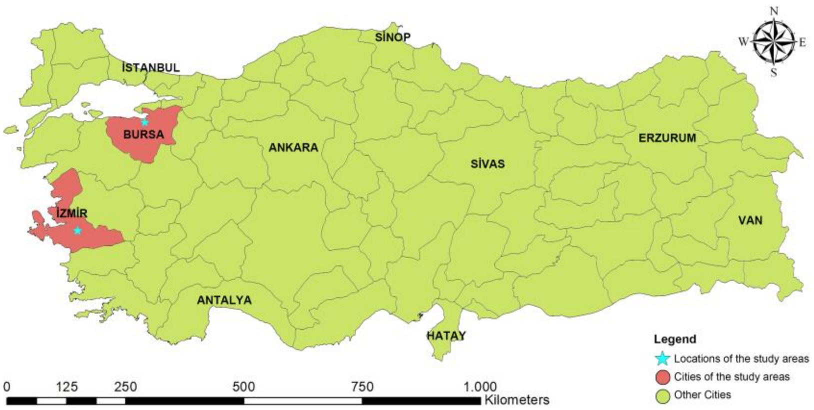


Figure 1. Study areas, Osmangazi and Dağtekke FECs

2.1.1. Osmangazi Forest Enterprise Chief

One of the field measurements conducted within the scope of the study was carried out in a Turkish red pine (Pinus brutia) stand located within the Osmangazi FEC in Bursa (Figure 2). The total area of Osmangazi FEC is 30,487.3 hectares, of which 10,842.1 hectares are forest land—5,942.5 hectares classified as forest and 3,337.7 hectares as degraded forest (Table 1).

2.1.2. Dağtekke Forest Enterprise Chief

The other field measurements conducted within the scope of the study was carried out in a Turkish red pine (Pinus brutia) stand located within the Dağtekke FEC in İzmir (Figure 3). The total area of Dağtekke FEC is 26,991.50 hectares, of which 7,974.5 hectares are forest land-6,114.5 hectares classified as forest and 1,860.0 hectares as degraded forest (Table 2).

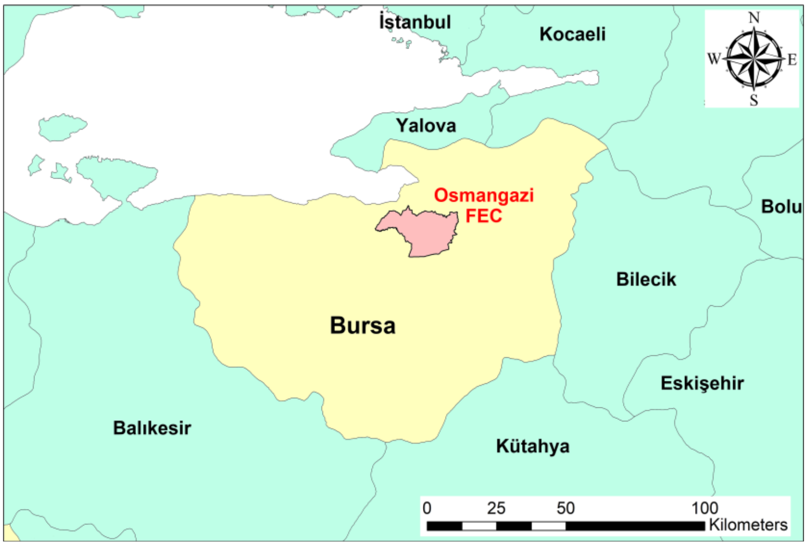


Figure 2. Osmangazi FEC

Table 1. Osmangazi FEC's forest classification (General Directorate of Forestry, n.d.-a)

Forest Management Chiefdom	Productive Forest (Ha)	Degraded Forest (Ha)	Total Forest Area (Ha)	Non-Forested Area (Ha)	Total Area (Ha)
Arasdere	4251	697,9	6359,4	2095,5	8454,9
Bursa	2343,8	336,5	2783,1	8450,1	11233,2
Çalı	6746,7	1608,5	8781,4	12859	21640,4
Kayapa	7927,7	2598,8	11676,9	18162	29838,9
Kazancı	5518,5	1202,7	7469	6498,2	13967,2
Kestel	4300,2	4428,6	9323,3	6902	16225,3
Mudanya	8150,9	1391	10509,6	27271,6	37781,2
Osmangazi	5942,5	3337,7	10842,1	19645,2	30487,3
Soğukpınar	4009,4	635,1	4860,9	1885,9	6746,8
Uludağ	6858,2	1431,4	8640,6	2542,8	11183,4
Yıldırım	5610,2	562,3	6429	3560	9989

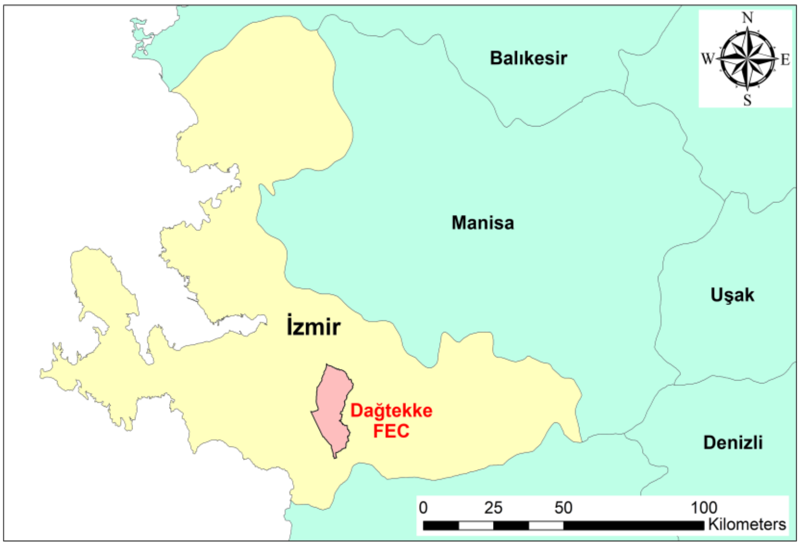


Figure 3. Dağtekke FEC

Table 2. Dağtekke FEC's forest classification (General Directorate of Forestry, n.d.-b)

Forest Management Chiefdom	Productive Forest (Ha)	Degraded Forest (Ha)	Total Forest Area (Ha)	Non-Forested Area (Ha)	Total Area (Ha)
Çeşme	5417,0	19243,0	24660,0	24258,5	48918,5
Dağtekke	6114,5	1860,0	7974,5	19017,0	26991,5
Gaziemir	5217,0	2165,0	7382,0	9984,5	17366,5
Güzelbahçe	4127,0	5492,0	9619,0	13732,0	23351,0
Karaburun	4316,0	21292,0	25608,0	19647,0	45255,0
Menderes	6663,5	5810,5	12474,0	12481,5	24955,5
Özdere	7846,0	17190,0	25036,0	16423,0	41459,0
Seferihisar	6692,5	9024,0	15716,5	17374,0	33090,5
Torbalı	3127,0	5287,0	8414,0	21553,0	29967,0
Urla	9598,5	17641,0	27239,5	13068,0	40307,5
Yeniköy	6776,5	1078,0	7854,5	2867,5	10722,0
Toplam	65895,5	106082,5	171978,0	170406,0	342384,0

2.2. Equipment and Machines

During the study, the PCE-PCO-2 particle counter was used to measure machine-related risk factors (Figure 4). The technical specifications of the measuring device are provided in Table 3.

Figure 4. PCE-PCO-2 particle counter

Table 3. PCE-PCO-2 particle counter specification (PCE Instruments)

Technical Specifications	Values
Particle Size Channels	0.3 - 0.5 - 1.0 - 2.5 - 5.0 - 10 µm
Flow Rate	0.1 ft³ (2.83 L/min), controlled by internal pump
Counting Modes	Cumulative, Differential, Concentration
Counting Efficiency	50% @ 0.3 µm; 100% for particle sizes > 0.45 µm
Coincidence Loss	5% @ 2,000,000 particles/ft³
Air Temperature	-14 to 140ºF (-25 to 60ºC); Accuracy: ±2ºF / ±1ºC
Relative Humidity	0 to 100% RH; Accuracy: ±3% RH (in the 40% to 60% RH range)
Dew Point / Wet Chamber	32 to 122ºF (0 to 50ºC)
Dimensions / Weight	9.4 x 3 x 2.2 in (240 x 75 x 57 mm) / 1.26 lbs (570 g)

During the skidding operations carried out within the boundaries of the Osmangazi FEC, a New Holland TT55B agricultural tractor was used. The technical specifications of the machine are provided in Table 4. A total of 180 minutes of measurement was conducted for particulate matter. The operations were carried out at 25°C under cloudy weather conditions.

Table 4. New Holland TT55B agricultural tractor specification (LECTURA GmbH)

Technical Specifications	Values
Engine Power	40.25 kW
Transport Length	3.64 m
Transport Width	1.925 m
Transport Height	2.2 m
Travel Speed	30 km/h
Weight	2.37 t
Steering	h
Engine Type	S8000
Displacement	2.931 L
RPM at Maximum Torque	1375 rpm
Maximum Torque	210 Nm
Number of Cylinders	3

During the skidding operations carried out within the boundaries of the Dağtekke FEC, a Türk-FIAT 80-66 model tractor was used. The technical specifications of the machine are provided in Table 5. A total of 130 minutes of measurement was conducted for particulate matter. The operations were carried out at 35°C under slightly cloudy and clear weather conditions.

Table 5. Specifications of Türk-FIAT 80-66 farm tractor (Türk Traktör A.Ş.)

Technical Specifications	Values
Manufacturer	Türk Traktör A.Ş.
Model	Türk-FIAT Wheeled Tractor 80-66 / 12+12
Maximum Loaded Weight (kg)	5,700
Wheelbase (m)	2.305
Engine Type	TÜMOSAN Diesel, 4-stroke, 4-cylinder
Power	80 hp (DIN), 85 hp (BS)
Revolutions per Minute	2,500 rpm
Maximum Torque	1,500 rpm – 242.4 Nm
Engine Displacement (L)	3.908
Dimensions (mm)	3735 (length), 1970–2470 (width), 2540 (height)

Particulate matter (PM10) was measured from the breathing zone of the tractor operator during skidding (Figure 5). In these types of studies, measurements are made from the breathing zone (Leszczynski, 2014).

Figure 5. PM10 measurement in operator’s breathing zone

3. RESULTS AND DISCUSSION

In the Osmangazi and Dağtekke FECs studies, particulate matter (PM2.5) risk was measured on agricultural tractors New Holland TT55B and Türk-FIAT 80-66, respectively. The tractors do not have enclosed cabins. Accordingly, the statistical data obtained from the measurements are presented in Table 6.

Table 6. PM2.5 Statistics from Osmangazi and Dağtekke FECs

Machine	N	Minimum	Maximum	Mean	Std, Deviation
New Holland TT55B (PM2.5)	180	88	335	206,22	69,45
Türk-FIAT 80-66	130	57	286	114,98	37,70

When the statistical data of the study were examined, an average PM2.5 concentration of 206.22 micrograms was obtained from the New Holland TT55B agricultural tractor, and 114.98 micrograms from the Türk-FIAT 80-66 agricultural tractor. Based on this, the classification of these values was evaluated according to the Air Quality Index (AQI) of the United States Environmental Protection Agency (Table 7). The value of 206.22 micrograms obtained from the New Holland TT55B falls within the PM2.5 range of 125.5 – 225.4 micrograms, which corresponds to the “Very Unhealthy” category. On the other hand, the value of 114.98 micrograms obtained from the Türk-FIAT 80-66 falls within the PM2.5 range of 55.5 – 125.4 micrograms, which corresponds to the “Unhealthy” category.

During tractor-based skidding operations, mechanical interaction between the machinery and dusty ground surfaces results in the release of PM2.5 particles into the air, concentrating particularly in the breathing zone of operators and thereby increasing their exposure levels. In such working environments, it is essential that operators use masks compliant with the EN 149 standard, which effectively filter airborne dust and particulates to protect the respiratory system (Rasekh et al., 2024). Establishing air quality monitoring stations at production sites will enable continuous tracking of PM2.5 concentrations, ensuring that timely preventive actions can be taken (Cooper and MacFarlane, 2023; Huang, 2023).

Table 7. Air Quality Index (Environmental Protection Agency, 2025)

PM2.5 (µg/m³)	PM10 (µg/m³)	AQI Value	Air Quality	Description
0.0 – 9.0	0-54	0-50	Good	Air quality is considered satisfactory; air pollution poses little or no risk.
9.1 – 35.4	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.
35.5 – 55.4	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.
55.5 – 125.4	255-354	151-200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
125.5 – 225.4	355-424	201-300	Very Unhealthy	Health alert: everyone may experience more serious health effects.
225.5 – 325.4	425-604	301-500	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.
325.5 and above	605 and above	501 and above	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.

4. CONCLUSIONS

Fine particulate matter generated during forest production activities particularly PM2.5 poses a significant occupational health risk. This threat becomes more pronounced under dry and windless weather conditions. To mitigate PM2.5 exposure, several operational measures can be implemented. These include shift-based work scheduling, adjusting working hours according to temperature and weather conditions, and ensuring adequate rest periods for workers. Technical precautions also play a critical role in controlling emissions during forestry production. In logging and chipping operations, it is recommended to use electric equipment with low dust emissions, perform cutting activities under humid weather conditions, and apply precise cutting techniques. Specifically, for skidding operations, the spread of PM2.5 can be significantly reduced by pre-wetting the soil surface, applying stabilizing materials to tractor trails, and if feasible integrating water-spraying systems. Furthermore, the use of emission-reducing filter systems in chipping machines and the application of water to work areas to suppress dust dispersion have proven to be effective strategies. In the long term, careful planning of forestry activities can help avoid unnecessary interventions, while promoting biological control methods can enable pest management without the use of chemicals. Raising awareness among both the workforce and the broader community is also vital. Providing forestry workers with regular training on the health effects of PM2.5 and appropriate mitigation methods supports the adoption of environmentally friendly practices.

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. 2025. National Ambient Air Quality Standards (NAAQS) table. Retrieved May 19, 2025, from https://www.epa.gov/criteria-air-pollutants/naaqs-table

General Directorate of Forestry. (n.d.-a). *Forest assets – Bursa Regional Directorate of Forestry*. Republic of Türkiye Ministry of Agriculture and Forestry. https://www.ogm.gov.tr/bursaobm/ormanlarimiz/orman-varligi

General Directorate of Forestry. (n.d.-b). *Forest assets – İzmir Regional Directorate of Forestry*. Republic of Türkiye Ministry of Agriculture and Forestry. https://www.ogm.gov.tr/izmirobm/ormanlarimiz/orman-varligi

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.

LECTURA GmbH. *New Holland TT55 technical data and specifications (2018–2025)*. LECTURA Specs. https://www.tr.lectura-specs.com/tr/model/tarim-makinalari/traktorler-4wd-new-holland/tt55-11708142, Accessed May 21, 2025.

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.

PCE Instruments. *PCE-PCO 2 particle counter*. https://www.pce-instruments.com/turkish/oel_uem-teknolojisi/oel_uem-cihazlarae/hijyen-gae_da-oel_uem-cihazae_-pce-instruments-gae_da-oel_uem-cihazae_-pce-pco-2-det_5852739.htm, Accessed May 21, 2025.

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.

Türk Traktör A.Ş. *Company profile and technical specifications* [PDF]. Chamber of Mechanical Engineers. https://www.mmo.org.tr/sites/default/files/T%C3%BCrk%20Trakt%C3%B6r%20A.%C5%9E.4.pdf, Accessed May 21, 2025.

Assessing the Carbon Dioxide Sequestration Effect of Improved Wood Utilization in Japan and Taiwan

Yasushi Suzuki[1*], Chien-Chih Liu[2], Kai Moriguchi[3]

[1]Faculty of Agriculture and Marine Science, Kochi University, Nankoku, Japan
[2]Division of Agriculture and Marine Science, Graduate School of Integrated Arts and Sciences, Kochi University, Nankoku, Japan
[3]Faculty of Agriculture, Shinshu University, Ina, Japan
*ysuzuki@kochi-u.ac.jp

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: *CO_2 sequestration; timber; improved use; LCA; forest utilization.*

1. INTRODUCTION

Sequestering CO_2 through forest growth and storing it over time in wood materials is an important method of mitigating global climate change. In Japan, dwellings are one of the major uses of wood material (Forestry Agency, 2017 and 2025). The authors began a funded research project developing an approach to designing forest and forestry policies that enhance forests' carbon sequestration benefits (National Institute of Informatics, 2025). As part of the project, the need to assess the effect of CO_2 assimilation by converting non-timber buildings to timber buildings in Japan has emerged. This paper assesses this effect by improving upon the method previously reported by Okazaki and Okuma (1998), examining not only Japan but also Taiwan. Recently, Taiwan began a trial to enhance plantation forestry, and the use of wood products is a current problem in Taiwanese forestry (Liu and Suzuki, 2025).

Plantation forests store carbon through growth by sequestering CO_2 in wood. After harvesting, the trees are transformed into wood products, such as houses and furniture. These wood products hold carbon throughout their lifespan (Figure 1, based on the original figures from Okuma, 2012, and the Forestry Agency, 2017).

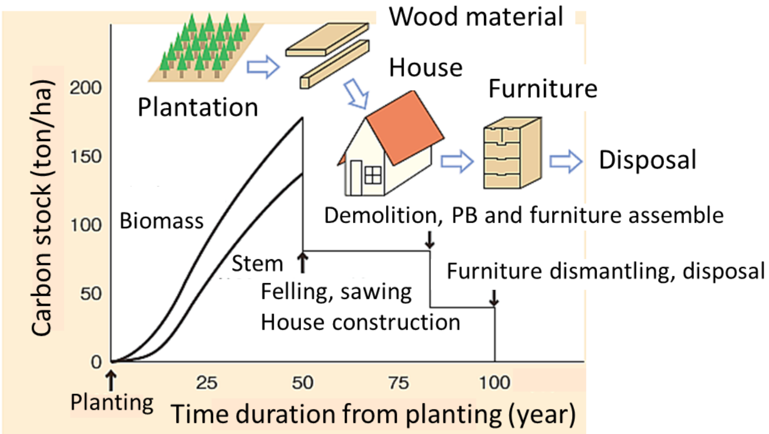


Figure 1. Carbon Stock Through Wood Utilization (Okuma, 2012; Forestry Agency, 2012)

Around the 2000s, LCA studies on log and sawlog production emerged in Japan. For example, Yoshioka et al. (2006) first completely estimated the energy consumption and CO_2 emissions from harvesting a typical coniferous plantation forest in northeastern Japan using the LCA approach. Iwaoka and Hifumi (2008a, 2008b) also calculated CO_2 emissions from various forest management and harvesting operations using the LCA method. Building on these achievements, Nakahata et al. (2011) estimated CO_2 emissions from more general forest management and harvesting operations in greater detail. Regarding forest products, Hitoe et al. (2013) and Hitoe (2014a, 2014b) completely analyzed the CO_2 emissions of log and sawlog production using the LCA approach. Hitoe (2014b) concluded that the CO_2 emissions through the total production process of logs and sawlogs were 11.1 and 287 kg CO_2/m^3, respectively.

This paper estimates the carbon stock of a typical wooden house (W) and a steel prefabricated house (S) in Japan, expressed in tons of CO_2 per house. Using an LCA database, CO_2 emissions through production, including materials, construction, and deposition, were obtained for both types of houses. Then, the effect of converting an S house into a W house was estimated by comparing the CO_2 stocks and emissions.

2. MATERIALS AND METHODS

2.1 Carbon Dioxide Assimilation via Forests in Japan

First, this study will provide useful information on how CO_2 assimilation is evaluated in Japanese forests. General information on Japanese forests related to CO_2 sequestration is summarized using basic data from the Forestry Agency (2025) and Zenrinkyou (2025).

2.2 Assessing the Effect of Converting Steel Houses to Wood Houses on CO_2 Storage in Japan

We used official data from Japanese government agencies, such as the Forestry Agency, the Ministry of Agriculture, Forestry and Fisheries, and the Ministry of Land, Infrastructure, Transport and Tourism, to obtain the data necessary to assess carbon storage in the average Japanese dwelling house. This includes the average floor area, average wood material volume, total wood material volume used for construction by tree species, and the average dry density of wood material by tree species. By combining these data with a conversion factor of wood material mass to carbon (C), as well as carbon to carbon dioxide (CO_2), we estimated the amount of CO_2 stored per house, for both wood houses (W) and steel houses (S).

The CO_2 emissions of wood (W) and steel (S) houses are estimated as follows: In Japan, life cycle assessment (LCA) databases for various products are available through commercial LCA software. For this study, we used the AIST-IDEA (version 2) LCA database included in the MiLCA software (MiLCA, 2025). This database provides various types of LCA data based on environmental effect standards. For CO_2 emissions from constructing wood and steel houses, we selected the LIME (life cycle impact assessment method based on endpoint modeling) method 2. Then, we estimated the environmental impact of converting a steel house to a wood house by comparing the CO_2 stock and emission differences for both types of houses.

2.3 Assessing the Possible Effect of Converting Steel Houses to Wood Houses on CO_2 Storage in Taiwan

First, the trend of wood material usage in Taiwan is reviewed through related references, such as Inoue (2017), Kawai (2021a, b; 2023), and the Japan Wood Products Export Association (2023). After summarizing the review and considering the results of the assessment of the effect of converting steel houses to wood houses on CO_2 storage in Japan, the possible effects of such a conversion in Taiwan are discussed.

3. RESULTS AND DISCUSSION

3.1 Carbon Dioxide Assimilation via Forests in Japan

In Japan, the growth of forest stem biomass ranges from 2 to 10 $m^3\ ha^{-1}\ year^{-1}$, while the dry density of wood ranges from 0.3 to 0.5 $t\ m^{-3}$ (Table 1). Applying a carbon (C) percentage of 0.5 per wood (Forestry Agency, 2023), the carbon stock growth should be between 0.3 and 2.5 tons of carbon per hectare per year ($t\text{-}C\ ha^{-1}\ year^{-1}$).

Table 1. General Information on Forests in Japan Related to CO_2 Sequestration

Item	Value	Unit
Stem biomass growth of forests	2 – 10	[$m^3 \cdot ha^{-1} \cdot year^{-1}$]
Dry density of wood	0.3 – 0.5	[$t \cdot m^{-3}$]
Percentage of carbon in wood*	0.5	
Carbon stock growth	0.3 – 2.5	[$t\text{-}C \cdot ha^{-1} \cdot year^{-1}$]
Conversion factor from C to CO_2	44/12	
CO_2 stock growth of forests	1.1 – 9.2	[$t\text{-}CO_2 \cdot ha^{-1} \cdot year^{-1}$]
Forest area in Japan	25	[million ha]
– Natural forest	15	[million ha]
– Plantation forest	10	[million ha]

*: Forestry Agency, 2023.

The conversion factor from C to CO_2 is 44/12. Thus, the CO_2 stock growth of forests in Japan would be 1.1–9.2 t CO_2 ha^{-1} $year^{-1}$. Japan's forest area is 25 million hectares, consisting of 15 million hectares of plantation forests and 10 million hectares of natural forests (Forestry Agency 2025).

The effects of CO_2 sequestration were recently evaluated and priced by a carbon credit scheme called J-Credit (Ministry of Economy, Trade and Industry, 2025). The process requires certification of sound forest management and incurs certain costs. Although it varies by case, the price seems to trade around 10,000 Japanese yen per ton of CO_2 per hectare per year (Zenrinkyou, 2025). In fiscal year 2023, the total amount of forest-related transactions in J-Credit was 8,200 t-CO_2, with an average price of 5,868 JPY/t-CO_2 (Forestry Agency, 2025), which was nearly equivalent to 55,000 KRW and 40 USD in June 2025.

3.2 The Effect of Converting Steel Houses to Wood Houses on CO_2 Storage in Japan

Table 2 lists the materials and labor required for construction per 10 m² of total floor area. The total column calculates the amount of materials listed, such as cement and ready-mixed concrete. The four columns on the right are classified by structure: wood (W), steel and reinforced concrete (SRC), reinforced concrete (RC), and steel (S). According to the table, the amount of timber used for a wood house and a steel house should be 0.197 and 0.026 m³/floor area m², respectively. These figures represent wood stock in cubic meters per floor area in square meters.

Talble 2. Area Base Unit (National) corresponds to the Construction Statistical Classification by Structure (per 10 m² of total floor area)

Material/Item	Unit	Total	Wood (W)	Steel and reinforced concrete (SRC)	Reinforced concrete (RC)	Steel (S)
Cement	t	1.52	0.81	3.04	3.08	1.55
Ready-mixed concrete	m^3	4.16	2.26	8.80	8.78	4.04
Construction aggregate, stone	m^3	6.52	4.05	10.85	11.11	7.09
Timber	m^3	1.02	1.97	0.35	0.36	0.26
Steel	t	0.78	0.10	2.33	1.09	1.36
Labor	person-day	19.02	19.08	33.05	22.04	17.12

Source: Ministry of Land, Infrastructure, Transport and Tourism, 2023.

To convert timber volume to an equivalent amount of CO_2, dry density information is required, which varies by tree species. Table 3's first row shows the dry density of the five most popular timber species in Japan: Japanese cedar (*Cryptomeria japonica*), Japanese cypress (*Chamaecyparis obtusa*), Japanese red pine (*Pinus densiflora*)/Japanese black pine (*Pinus thunbergii* Parl.), Japanese larch (*Larix kaempferi*), and Yezo spruce (*Picea jezoensis*)/Sakhalin fir (*Abies sachalinensis*) (Center for Global Environmental Research, National Institute for Environmental Studies, 2025). Using log production for sawn lumber and veneer (Ministry of

Agriculture, Forestry and Fisheries, 2025), which represent the most common construction uses, the average dry density, weighted by produced species, is 0.340 t/m³.

Table 3. Log Production for Construction by Species with Dry Density

Item and species	Japanese cedar (*Cryptomeria japonica*)	Japanese cypress (*Chamaecyparis obtusa*)	Japanese Red Pine (*Pinus densiflora*), Japanese Black Pine (*Pinus thunbergii* Parl.)	Japanese Larch (*Larix kaempferi*)	Yezo spruce (*Picea jezoensis*), Sakhalin fir (*Abies sachalinensis*)	Source
Dry density (t/m^3)	0.31	0.41	0.45	0.40	0.32	Center for Global Environmental Research, National Institute for Environmental Studies, 2025
A) Log production for saw timber (x1000 m^3)	8,120	2,320	74	824	801	Ministry of Agriculture, Forestry and Fisheries, 2025.
B) Log production for veneer (x1000 m^3)	2,163	622	152	731	200	Ministry of Agriculture, Forestry and Fisheries, 2025.
Log production for construction (A + B)	10,283	2,942	226	1,555	1,001	
Average dry density, weighted by produced species (t/m^3)	0.340					

Using the information obtained from Tables 1, 2, and 3, the reduction in CO_2 emissions from converting from steel to wood house materials was estimated as follows (Table 4). The first row of Table 4 shows the amount of timber used for a steel house (S) and a wood house (W), as shown in Table 2. Since the average floor area is 118.25 m³ per house (Ministry of Land, Infrastructure, Transport and Tourism, 2025) [2. of Table 4], the timber amount per house [3. of Table 4] can be calculated by multiplying [1.] by [2.]. The timber dry weight per house is obtained by multiplying [3.] by the dry density of timber [4. of Table 4], which was obtained in Table 3. Since the conversion factor of timber dry weight to carbon is 0.5 (Table 1), the carbon stock per house can be calculated by multiplying [5.] by 0.5. The carbon dioxide stock per house is obtained by multiplying [5.] by the conversion factor of 44/12 (Table 1). Let the CO_2 stock per steel house be C (1.915 tons of CO_2) and per wood house be D (14.509 tons of CO_2).

In the LCA database AIST-IDEA, the CO_2 emissions per floor area (t-CO_2/m²) through the manufacturing of steel and wood houses are listed as 0.602 and 0.455, respectively [8. of Table 4]. Therefore, the CO_2 emissions per house can be estimated by multiplying [8.] by [2.] to get 71.13 (A) and 53.83 (B) t-CO_2/m², respectively [9. of Table 4]. Note that the CO_2 stock of a wood house (14.509 t-CO_2/house) is much smaller than the emission through manufacturing (53.83 t-CO_2/house).

Table 4. Estimation of CO_2 Emission Reduction by House Material Conversion from Steel to Wood

Item	Steel (S)		Wood (W)		Source / Calculation
1. Timber [m^3/m^2]		0.026		0.197	Ministry of Land, Infrastructure, Transport and Tourism. 2023.
2. Floor area [m^2]		118.25		118.25	Ministry of Land, Infrastructure, Transport and Tourism. 2025.
3. Timber per house [m^3]		3.075		23.295	1. x 2.
4. Dry density of timber [t/m^3]		0.340		0.340	Average dry density, weighted by produced species (Table 3)
5. Timber dry weight per house [t]		1.044		7.914	3. x 4.
6. Carbon stock per house [t-C]		0.522		3.957	5. x 0.5
7. CO_2 stock per house [t-CO_2]	C	1.915	D	14.509	6. x (44/12)
8. Emission per floor area [t-CO_2/m^2]		0.602		0.455	AIST-IDEA, LIME-2 JPN (MiLCA, 2025.)
9. Emission per house [t-CO_2]	A	71.13	B	53.83	8. x 2.
10. CO_2 emission reduction by house material conversion [t-CO_2]		29.89			(D - B) - (C - A)

However, the difference between the steel house (C: 1.915 t-CO_2 versus A: 71.13 t-CO_2) is larger than that of the wood house. Finally, the reduction in CO_2 emissions from converting from a steel house to a wood house can be estimated by (D – B) – (C – A), which is 29.89 t-CO_2/house [10. of Table 4].

According to the Ministry of Land, Infrastructure, Transport and Tourism (2025), there are 65 million existing dwellings in Japan. From 2012 to 2014, the ratio of newly constructed wooden floor area to total newly constructed floor area remained stable or increased slightly (Forestry Agency, 2025). Converting one percent of Japan's newly constructed non-wood floors, equivalent to 0.3 million square meters (equivalent to 2,500 houses), to wood floors would reduce CO_2 emissions by 75,000 tons, nearly equal to the annual sequestration of average Japanese forests (Table 1) of 25,000 hectares. There is also a trend of constructing large public buildings using high strength wood materials such as CLT (Closs Laminated Timber) in Japan (Forestry Agency, 2025).

3.3 The Possible Effect of Converting Steel Houses to Wood Houses on CO2 Storage in Taiwan

Since the 1990s, Taiwan has had strict conservation policies that limited the use of forest resources for materials. However, after the governing party changed in 2017, the policy shifted towards aggressive utilization of forest resources (Liu and Suzuki, 2025). Nevertheless, Taiwan's subtropical climate and cultural preference for non-wood buildings persist (Inoue, 2017; Kawai, 2021a, b, 2023; Japan Wood Products Export Association, 2023). Typically, buildings in Taiwan, even those that use more timber than ordinary buildings, have a ground floor made of reinforced concrete (RC) and upper floors made of timber. The percentage of wood houses among all dwellings is less than one percent. Wood is preferred for interior materials and furniture (Inoue, 2017; Kawai, 2021a, b, 2023; Japan Wood Products Export Association, 2023). The current generation of Taiwanese people is not very familiar with traditional wood use and wooden structures. Therefore, in the long term, educating young Taiwanese people about forests, forestry, and forest products may be key to substantially increasing timber use in Taiwanese society.

4. CONCLUSIONS AND SUGGESTIONS

Although previous estimates concluded that wooden houses store significant amounts of carbon (Okazaki and Okuma, 1998), recent life cycle assessment (LCA) data suggest that the CO_2 emissions from manufacturing wooden houses would far exceed their CO_2 storage capacity. However, converting steel houses to wood houses, especially in new constructions, has a considerable effect on reducing CO_2 emissions because manufacturing wood houses emits much less CO_2 than manufacturing steel houses. In Japan, despite the decreasing population, there are still many existing houses and a demand for new construction. Therefore, converting steel houses to wood houses would reduce CO_2 emissions to some extent.

In the case of Taiwan, the positive factor for prospective timber use is the recent policy change from strict forest conservation to the aggressive use of planted forests. However, the subtropical climate and cultural background may negatively affect timber use growth. One possible solution would be to educate the new generation.

ACKNOWLEDGEMENTS

This research was supported by JSPS KAKENHI Grant Number 24K03148.

REFERENCES

Center for Global Environmental Research, National Institute for Environmental Studies. 2025. [CGER-I174-2025] National Greenhouse Gas Inventory Document of JAPAN, 2025 | CGER Reports | Center for Global Environmental Research. Online, (https://cger.nies.go.jp/publications/report/i174/en/). Accessed June 21, 2025.

Forestry Agency. 2017. Forest and Forestry White Paper FY2016. Online, (https://www.rinya.maff.go.jp/j/kikaku/hakusyo/28hakusyo/index.html). Accessed August 4, 2025.

Forestry Agency. 2021. Guideline for carbon stock index for timber used for buildings. Online, (https://www.rinya.maff.go.jp/j/mokusan/mieruka.html). Accessed August 2, 2025.

Forestry Agency. 2025. Forest and Forestry White Paper FY2024. Online, (https://www.rinya.maff.go.jp/j/kikaku/hakusyo/r6hakusyo/index.html). Accessed June 22, 2025.

Hitoe, K. 2014a. A Literature Review of Life Cycle Assessment Study in Wood, Wooden Material and Wood Fuel. Journal of Life Cycle Assessment, Japan. 10(4): 488–491. DOI: https://doi.org/10.3370/lca.10.488.

Hitoe, K. 2014b. Study on Life Cycle Assessment of Domestic Logs, Lumber and Effective Use of Sawmill Residues to Energy. Dissertation, Doctor of Philosophy (Agriculture), Tokyo University of Agriculture and Technology, Fuchu. 89p. Online, (http://hdl.handle.net/10636/461). Accessed June 22, 2025.

Hitoe, K., Hasegawa, T., Hasegawa, K., Terazawa, K., Yamanaka, K. and Hattori, N. 2013. Case Study of Life Cycle Assessment of Domestic Logs. Mokuzai Gakkaishi. 59(5): 269–277. DOI: https://doi.org/10.2488/jwrs.59.269.

Inoue, M. 2017. Trend of demand and supply of wood and manufacturing and needs of veneer etc. in Taiwan. Wood Products Information, May 2017: 19–22.

Iwaoka M., Hifumi, M. 2008a. The energy consumption and the amount of carbon dioxides emission, in timber production operations (1). Journal of the Forestry Mechanization Society. 654: 1–7.

Iwaoka M., Hifumi, M. 2008. The energy consumption and the amount of carbon dioxides emission, in timber production operations (2). Journal of the Forestry Mechanization Society. 655: 1–6.

Japan Wood Products Export Association. 2023. Wood demand and supply, wood industry, and status and trend of wood market in Taiwan. Japan Wood Products Export Association, Tokyo. 46p. Online, (https://www.j-wood.org/info/230623/t.pdf). Accessed June 23, 2025.

Kawai, Y. 2021a. Current status and future possibilities of timber exports to Taiwan (No. 1). Wood Protection. 47(5): 239–246. DOI: https://doi.org/10.5990/jwpa.47.239.

Kawai, Y. 2021b. Current status and future possibilities of timber exports to Taiwan (No. 2). Wood Protection. 47(6): 269–273. DOI: https://doi.org/10.5990/jwpa.47.269.

Kawai, Y. 2023. The technical consideration of moisture control on wood products exports to Taiwan. Wood Protection. 49(5): 201–205. DOI: https://doi.org/10.5990/jwpa.49.201.

Liu, C., Suzuki, Y. 2025. Analysis of Forestry Operational Efficiency and Recommendations for Application in Taiwan Based on Empirical Cases in Japan. I*n*: BOOK OF ABSTRACTS - International Conference of KSFE-FETEC 2025, June 30 - July 2 2025, Hoam Faculty House of Seoul National University, Seoul, Korea. Korean Society of Forest Engineering (KSFE), Seoul, Korea. 118p.: 71.

MiLCA. 2025. LCA software MiLCA. Online, (https://www.milca-milca.net/). Accessed June 22, 2025.

Ministry of Agriculture, Forestry and Fisheries. 2025. Report on wood demand and supply. Online, (https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00500217&tstat=000001014476&cycle=7&year=20230&month=0&tclass1=000001014477&tclass2=000001215720). Accessed June 20, 2025.

Ministry of Economy, Trade and Industry. 2025. J-Credit Scheme. Online, (https://japancredit.go.jp/english/). Accessed June 21, 2025.

Ministry of Land, Infrastructure, Transport and Tourism. 2023. Survey on the actual demand for construction materials and labor, FY2021. Online, (https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00600040&tstat=000001017724&cycle=8&year=20211&month=0&result_back=1&tclass1val=0). Accessed June 20, 2025.

Ministry of Land, Infrastructure, Transport and Tourism. 2025. Data related to duelling economy, FY 2024. Online, (https://www.mlit.go.jp/statistics/details/t-jutaku-2_tk_000002.html). Accessed June 20, 2025.

Nakahata, C., Komatsuzaki, M., Aruga, K., Takei, Y., Yamaguchi, R., Ito, K., Murakami, A., Saito, M., Tasaka, M. 2011. Carbon-dioxide emission estimations and balance analysis on forestry operations — Case study of forestry enterprises in Tochigi Prefecture. Journal of the Japan Forest Engineering Society. 26(3): 187–194.

National Institute of Informatics. 2025. KAKEN — Research Projects | Developing the approach for designing forest and forestry policies to enhance the carbon sequestration benefits of forests (KAKENHI-PROJECT-24K03148). Online, (https://kaken.nii.ac.jp/en/grant/KAKENHI-PROJECT-24K03148/). Accessed August 2, 2025.

Okazaki, Y., Okuma, M. 1998. Evaluation of Wooden House Construction from the Standpoint of Carbon Stock and CO_2 Emission. Wood Industry. 53(4): 161–165.

Okuma, M. 2012. Desirable connection of forest and forestry to wood utilization. Sanrin. 1541: 2–9.

Yoshioka, T., Aruga, K., Nitami, T., Sakai, H. and Kobayashi, H. 2006. A case study on the costs and the fuel consumption of harvesting, transporting, and chipping chains for logging residues in Japan. Biomass and Bioenergy. 30(4): 342–348. DOI: https://doi.org/10.1016/j.biombioe.2005.07.013.

Zenrinkyou. 2025. J-Credit Scheme for Practical Forestry Cases. Zenrinkyou, Tokyo. 192p.

Women Students in Forest Engineering Profession in the Context of Gender: A Case Study from Türkiye

Bekircan Balcı[1*], Murat Köse[2]

[1] Forest Engineering, Faculty of Forest, Bursa, Bursa Technical University, Türkiye
[2] Forest Engineering, Faculty of Forest, Bursa Technical University, Bursa, Türkiye
*bekircan.balci@btu.edu.tr

Abstract

Traditionally male-dominated, forest engineering has recently seen a rise in women's representation in both education and the profession. University education is a critical period during which students develop their professional identities and shape their career perceptions. This study examines the views of undergraduate students in the Department of Forest Engineering at Bursa Technical University on the profession, their assessments of acquiring professional competencies, and their perceptions of gender inequality. The perspectives of men students on these issues are also addressed. Survey data were collected from 205 students across different year groups and analyzed using descriptive statistics and difference tests. Findings reveal that women students exhibit more positive attitudes toward environmental protection, the preservation of natural habitats and wildlife, gender equality, and increased woman representation. In contrast, men students expressed more favorable views regarding the physical requirements of the profession and career security. The study highlights the importance of policies aimed at promoting gender equality within the profession.

Keywords: *Forest engineering, woman in forestry, gender equality, engineering, Türkiye.*

1. INTRODUCTION

Forestry, like farming and similar rural jobs that require physical strength, is mostly considered among male occupations (Brandth and Haugen, 2005) and is seen as dangerous, dirty and challenging (Garland, 2018). Additionally, the masculine culture of forestry (Brandth and Haugen, 1998; Koch and Matviichuk, 2021) and traditional prejudices and perceptions that women aren't suited to a physically demanding field (Burley, 2001; Brandth and Haugen, 2005; Andersson and Lidestav, 2016) are cited among the reasons for gender inequality. It has been noted that the prevalent norms and practices in the forestry sector are a male-dominated professional field, resisting attempts to diversify the corporate workforce (Andersson and Lidestav, 2016; Johansson et al., 2018). Forestry, like mining and construction, is among the occupational groups traditionally dominated almost entirely by men (Johansson et al., 2020).

In Canada, women representation in the forestry industry remains at 16% (Bardekjian et al., 2019). Employer survey results from the Greater Toronto Area forestry sector reveal that the proportion of women in the workforce ranges from just 0% to 9% (McCann and Raycraft, 2017). While women's representation in professional fields such as science, technology, and engineering in Türkiye is increasing, the faster increase in the number of man engineers leads to a continued male dominance in these fields (Yıldırımalp, 2021). The proportion of women engineers registered with the Chamber of Forest Engineers in Türkiye was recorded as 22.41% as of 2022 (UCTEA, 2023).

The perception of the forestry sector as a male-dominated field continues to be valid not only in workplaces but also in the context of forestry education (Larasatie et al., 2020). According to the American Society of Foresters, as of 2019, 23% of students enrolled in forestry programs were women (NASF, 2022). In Sweden, 20% of students studying in forest engineering programs in 2019 were women (Macinnis-Ng and Zhao, 2022). According to 2024 data in Türkiye, the rate of women students enrolled in forest engineering programs in 12 forestry faculties was 36.94% (CHE, 2024). At the same time, while women graduates in the Asia and Pacific region expressed that gender had a “medium” to “high” impact on their capacity to work in a forestry-related position, many teachers in Europe emphasized that graduates’ employment chances were significantly affected by gender (Rekola and Sharik, 2022). In Türkiye, men students from public high schools tend to choose the forest engineering department more than their women peers (Yurdakul Erol, 2022). This situation highlights the existence of gender-based differences and inequalities in forestry education. In this context, the primary objective of this study is to examine forestry engineering students' career perceptions of the profession, their expectations regarding the acquisition of professional competencies, and their attitudes toward gender-based inequalities within the profession. It also aims to analyze whether attitudes toward gender-based inequalities within the profession differ based on students' gender characteristics.

2. MATERIALS AND METHODS

The Forest Engineering Department of Bursa Technical University (BTU), Faculty of Forestry, was selected as the sample for this study. Within the scope of the educational model implemented in the departmental curriculum, students gain direct professional experience by working in forest enterprises or private forestry offices during the final semester (8th semester) of their undergraduate education, providing them with the advantage of early interaction with the sector. This faculty offers a meaningful example for evaluating the impact of applied training on the profession's perspective and gender perception within it. Furthermore, Bursa and its districts rank among the top provinces in terms of forest abundance among surrounding provinces. Because 45% of Bursa's surface area is covered by forests (GDF, 2024), it holds a significant position in terms of forestry activities and offers a suitable working environment for forest engineering education and professional practice. For these important reasons, the BTU Forest Engineering Department was selected as the sample. After the sample was selected, a survey form was prepared to be administered to 1st, 2nd, 3rd, and 4th year students studying in the department of forest engineering. The survey form was created in line with expert opinions and literature (Brandth and Haugen, 2005; Larasatie et al., 2020; Macinnis-Ng and Zhao, 2022; Yurdakul Erol, 2022). The survey form consists of four main headings. These are; (i) student profiles, (ii) views on profession and career, (iii) views on the development of professional skills, and (iv) perceptions of gender inequality in the profession. After the survey form was prepared, a preliminary survey was conducted, unclear questions were edited, and the survey form was finalized. Surveys were administered to a sample of 205 students at the end of the academic year. The distribution of surveyed students by grade level and gender is presented in Table 1.

Table 1. Class levels and gender distribution of the students surveyed.

Year of Study	Number of women students	Number of men students	Total
First-year	39(%19,02)	34(%16,59)	73(%35,61)
Second-year	23(%11,22)	18(%8,78)	41(%20)
Third-year	20(%9,76)	32(%15,61)	52(%25,37)
Fourth-year	19(%9,27)	20(%9,76)	39(%19,02)
Total	101(%49,27)	104(%50,73)	205(%100)

Before administering the survey, students were clearly and comprehensively informed about the purpose and scope of the study, and its voluntary nature. No personal data that could reveal the identity of any participants was collected; surveys were answered anonymously and individually, without mentioning their names. During the implementation, the researchers were present in the classrooms, directly observing the process, and ensuring that students completed the surveys of their own free will, carefully, and independently, without any directives. The data obtained from the survey, along with all qualitative and quantitative data obtained from official institutions and literature reviews, were used as material in this research.

Perspectives on professions and careers, as well as perspectives on acquiring professional qualifications, were analyzed using descriptive statistics. In this context, arithmetic means were calculated separately for men and women students and presented in tables. Furthermore, arithmetic means were presented for both genders regarding attitudes toward gender inequality in the profession, and a comparative analysis was conducted to determine whether differences existed between the genders. Because the data were not normally distributed, the nonparametric Mann–Whitney U test was used. All analyses were conducted using IBM SPSS Statistics (version 26.0).

3. RESULT AND DISCUSSION

In this section, the data obtained from the survey conducted within the scope of the research are analyzed and the findings regarding the students' perceptions of profession and career, their opinions on acquiring professional qualifications and their attitudes towards gender-based inequalities in the profession are included.

3.1. Perspective on Profession and Career

Within the scope of this heading, the responses given by the students to the statements aiming to measure their perceptions and evaluations of profession and career were analyzed; the arithmetic mean values for each statement are presented in Table 2.

Table 2. Expressions regarding profession and career perspective.

	Statements	Gender	Mean (M)	Overall mean
1	I find forest engineering an appealing profession due to its focus on nature, forests, and the environment	Women	4,19	4,18
		Men	4,17	
2	I consider the potential of forest engineering to address environmental problems important.	Women	4,03	4,08
		Men	4,13	
3	Forest engineering provides long-term job security and career advancement opportunities.	Women	3,72	3,86
		Men	3,99	
4	I consider forest engineering to be a profession capable of fulfilling my financial expectations	Women	3,51	3,59
		Men	3,66	
5	I believe this profession offers continuous opportunities for developing professional skills.	Women	3,73	3,77
		Men	3,80	
6	I find the physical requirements of fieldwork in forest engineering challenging for me.	Women	2,93	2,63
		Men	2,34	
7	The forest engineering profession also offers opportunities to increase society's environmental awareness.	Women	4,08	3,96
		Men	3,84	

8	I feel a sense of responsibility for the role of the forest engineering profession in combating global environmental problems.	Women	4,12	3,94
		Men	3,77	
9	The forest engineering profession is meaningful and valuable to me in terms of protecting natural habitats.	Women	4,42	4,24
		Men	4,08	
10	The forest engineering profession is meaningful and valuable to me in terms of wildlife conservation.	Women	4,33	4,20
		Men	4,07	
11	I think teamwork is important in the forest engineering profession.	Women	4,44	4,29
		Men	4,14	
12	This profession is meaningful to me in terms of meeting society's demands from forests.	Women	4,05	3,99
		Men	3,92	
13	While working in the forestry profession, I believe I will contribute to the sustainable management of the country’s forest resources.	Women	4,21	4,17
		Men	4,12	
14	I think I will encounter various issues in my profession such as fires, illegal logging, pest outbreaks, and forest-village relations.	Women	3,94	4,03
		Men	4,12	
15	I think that the professional problems I will encounter while doing my job may negatively affect my psychology.	Women	2,71	2,55
		Men	2,38	
16	I think there is a likelihood of encountering safety risks due to the requirement of working in the field in the forestry profession.	Women	3,58	3,53
		Men	3,48	
17	I believe my ability to manage social relations (with villagers, forest workers, government institutions) will be important in the forestry profession.	Women	4,33	4,24
		Men	4,16	
18	I think men are more likely to have an advantage in career planning (e.g., finding jobs, promotion) in the forestry profession.	Women	3,54	3,43
		Men	3,33	
19	I think the forestry profession is important in issues such as combating climate change and conserving biological diversity.	Women	3,77	3,80
		Men	3,83	
20	I think the forestry profession will be among the more attractive and preferred professions in the future.	Women	3,90	3,86
		Men	3,83	
21	The forest engineering profession has a positive image in society	Women	3,45	3,46
		Men	3,47	
22	I think the forestry profession is perceived as a male-dominated occupation.	Women	2,96	3,06
		Men	3,15	
23	I think women will take part in more challenging tasks in the forestry profession.	Women	2,94	3,09
		Men	3,24	

As can be seen in Table 2, when examining forest engineering students' perceptions of their professions and careers, it is seen that both men and women participants find the profession attractive due to its strong connection to nature, forests, and the environment, with only a slight difference in this regard (Mwomen=4.19; Mmen=4.17). Regarding the potential to contribute to solving environmental problems, men students' perception (M=4.13) is slightly higher than womens' (M=4.03). This finding is consistent with the findings of Arevalo et al.

(2012) that forestry students place high value on areas such as forestry, forest planning, environmental protection, climate change, and carbon sequestration, along with practical field experience, problem-solving, and teamwork skills.

The fact that women students (M=2.93) expected greater challenges than men students (M=2.34) regarding the physical demands of the profession is consistent with meta-analytic evidence demonstrating gender differences in interests: the "things-orientation" profile of engineering-like fields may lead to a relatively lower average interest among women (Su et al., 2009). Specifically, in forestry, persistent masculine norms in educational settings and experiences of harassment/discrimination (documented in the context of #MeToo) may negatively impact women's perceptions of the field's accessibility and comfort (Grubbström and Powell, 2020). In this study, it is also noteworthy that women students (M=2.71) reported higher levels of expectation of negative impacts than men students (M=2.38) regarding the psychological impact of professional challenges.

According to the research findings, the perception level regarding the protection of natural habitats was higher among women students (M=4.42) than men students (M=4.08). Similarly, the perception regarding the protection of wildlife was higher among women (M=4.33) than men (M=4.07).

When evaluating the profession's public image, it is seen that the scores of women (M = 3.45) and men (M = 3.47) students are close to each other and generally positive. While these averages are above the average score (M = 3.24) given in Yurdakul Erol's (2022) study regarding the profession's positive public image, the results of both studies are similar in terms of general trends.

3.2. Opinions on Acquiring Professional Qualifications

Under this heading, students' opinions and tendencies towards acquiring professional qualifications were evaluated; the averages of the responses given to the relevant statements are given in Table 3.

Table 3. Statements regarding acquiring professional qualifications.

	Statements	**Gender**	**Mean (M)**	**Overall Mean**
1	The practical courses provided in forestry education are more important for my profession than theoretical courses.	Women	4,52	4,40
		Men	4,27	
2	I believe that the content of the theoretical courses provided in forestry education is sufficient.	Women	3,34	3,27
		Men	3,20	
3	I believe that the number of theoretical courses provided in forestry education is sufficient.	Women	3,50	3,54
		Men	3,58	
4	I believe that the content of the practical courses provided in forestry education is sufficient.	Women	2,82	2,80
		Men	2,78	
5	I believe that the number of practical courses provided in forestry education is sufficient.	Women	2,58	2,50
		Men	2,42	

As can be seen from Table 3, students view applied courses as more professionally important than theoretical courses; women (M=4.52) agreed with this view more than men (M=4.27). However, women (M=2.82) and men (M=2.78) students found the content of applied courses insufficient. Similarly, women (M=2.58) and men (M=2.42) students also found the number of applied courses insufficient. This result suggests that applied courses are the most critical course type for students' professional competence, but the scope and number of these courses in the current curriculum don’t meet expectations.

3.3. Attitudes Towards Gender Inequality in Professional Careers

This section examines students' attitudes toward gender inequality in professional and career settings, and general trends are assessed based on the arithmetic means of the survey responses presented in Table 4. Furthermore, the Mann Whitney U test was used to investigate whether there were differences in attitudes toward gender inequality in professional careers based on student gender.

Table 4. Statements regarding gender inequality in professional careers.

	Statements	Gender	Mean (M)	Overall Mean	P value
1	I think women should be more supported to pursue a career in forest engineering.	Women	4,36	3,81	0,000
		Men	3,28		
2	Greater representation of women in the forestry sector will add innovation and diversity to the sector.	Women	4,44	3,91	0,000
		Men	3,40		
3	More awareness should be raised about gender equality in forest engineering education.	Women	4,32	3,80	0,000
		Men	3,30		
4	I believe that in the forest engineering profession, women's professional competencies are at the same level as men.	Women	3,89	3,48	0,000
		Men	3,08		
5	I think the challenges women face in the field of forest engineering are greater than those faced by men.	Women	3,95	3,65	0,001
		Men	3,37		
6	Greater participation of women in the forestry sector will contribute to gender equality.	Women	4,29	3,84	0,000
		Men	3,41		
7	I think women should be in more leadership positions in the forest engineering profession.	Women	4,39	3,72	0,000
		Men	3,08		
8	When choosing to work in the forest engineering profession, I also take into consideration the issue of gender equality in the sector.	Women	4,01	3,67	0,000
		Men	3,34		
9	I think women need to make more effort than men in the process of being employed in the forestry sector.	Women	3,70	3,30	0,000
		Men	2,91		

When participants' attitudes toward gender inequality in professional careers were examined, significant differences were identified between the perceptions of men and women students. According to the Mann Whitney U test results, there were statistically significant differences based on gender across all items ($p<0.05$).

When examining the data in Table 4, women students (M=4.36) showed significantly higher agreement than men students (M=3.28) that women's careers in forestry should be supported more. Similarly, women students (M=4.44) agreed more than men students (M=3.40) that women representation would contribute to innovation and diversity in the forestry sector. Larasatie et al. (2020) stated that women representation in forestry strengthens women students' sense of belonging to the sector and increases their career motivation. Therefore, the findings of this study confirm the importance of representation emphasized in the literature, demonstrating that women students have a higher awareness of the need for support and the contribution of diversity to the sector.

The view that women's awareness of gender equality should be increased in the vocational training process was supported at a higher level by women (M=4.32) than men (M=3.30).

The view that gender equality should be taken into account in career selection was more widely supported by women students (M=4.01) than men students (M=3.34). Furthermore, the perception that women need to exert more effort than men in the forestry sector to be employed was higher among women students (M=3.70) than men students (M=2.91).

4. CONCLUSION AND SUGGESTIONS

This study demonstrates that forest engineering students' perceptions of the profession indicate that a strong connection to nature, forests, and the environment are a significant attraction for all participants, but that some distinct gender differences emerge. Women students exhibited more positive attitudes than men students toward environmental protection, the preservation of natural habitats and wildlife, gender equality, and increasing women representation. In contrast, men students expressed more positive assessments of the profession's physical requirements and career security. Both genders viewed practical courses as the most critical element for professional competence, but a common view was that their content and number were insufficient. This highlights the need to strengthen practical learning opportunities in existing educational programs. Furthermore, gender perception differences provide important data for developing inclusiveness and equal opportunity policies within the profession. In this context, it is recommended to increase the scope and number of practical courses in forestry education, to make arrangements to balance the physical requirements in field work, to integrate educational content that will strengthen gender equality awareness into the program, and to implement inclusive policies that will support the participation of women students in the profession, their representation in leadership positions, and their career development.

REFERENCES

Andersson, E., Lidestav, G. 2016. Creating alternative spaces and articulating needs: Challenging gendered notions of forestry and forest ownership through women's networks. Forest Policy and Economics, 67: 38-44.

Arevalo, J., Mola-Yudego, B., Pelkonen, P., Qu, M. 2012. Students' views on forestry education: A cross-national comparison across three universities in Brazil, China and Finland. Forest Policy and Economics, 25: 123-131.

Bardekjian, A.C., Nesbitt, L., Konijnendijk, C.C., Lötter, B.T. 2019. Women in urban forestry and arboriculture: Experiences, barriers and strategies for leadership. Urban Forestry & Urban Greening, 46: 126442.

Brandth, B., Haugen, M.S. 1998. Breaking into a masculine discourse. Women and farm forestry. Sociologia Ruralis, 38(3): 427-442.

Brandth, B., Haugen, M.S. 2005. Doing rural masculinity – from logging to outfield tourism. Journal of Gender Studies, 14(1): 13-22.

Burley, J. 2001. Women in forestry and forest research. The International Forestry Review, 3(1): 64-68.

CHE. 2024. Council of Higher Education. https://yokatlas.yok.gov.tr/lisans-bolum.php?b=10163 (access date: 25.07.2025) (in Turkish).

Garland, J.J. 2018. Accident reporting and analysis in forestry: Guidance on increasing the safety of forest work. Forestry Working Paper, 2: 1-77.

GDF. 2024. General Directorate of Forestry. https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler (access date: 25.07.2025) (in Turkish).

Grubbström, A., Powell, S. 2020. Persistent norms and the #MeToo effect in Swedish forestry education. Scandinavian Journal of Forest Research, 35(5-6): 308-318.

Johansson, M., Johansson, K., Andersson, E. 2018. #Metoo in the Swedish forest sector: Testimonies from harassed women on sexualised forms of male control. Scandinavian Journal of Forest Research, 33(5): 419-425.

Johansson, K., Andersson, E., Johansson, M., Lidestav, G. 2020. Conditioned openings and restraints: The meaning-making of women professionals breaking into the male-dominated sector of forestry. Gender, Work & Organization, 27(6): 927-943.

Koch, S., Matviichuk, E. 2021. Patterns of inequality in global forest science conferences: An analysis of actors involved in IUFRO World Congresses with a focus on gender and geography. Forest Policy and Economics, 129: 102510.

Larasatie, P., Barnett, T., Hansen, E. 2020. The “Catch-22” of representation of women in the forest sector: The perspective of student leaders in top global forestry universities. Forests, 11(4): 419.

Macinnis-Ng, C., Zhao, X. 2022. Addressing gender inequities in forest science and research. Forests, 13(3): 400.

McCann, C., Raycraft, K. 2017. The Arboriculture Sector Partnership Planning Project: Findings Report. Toronto.

NASF (2022). https://www.stateforesters.org/2022/03/31/we-need-more-women-in-forestry-who-wouldnt-want-to-work-with-trees/ (access date: 25.07.2025).

Rekola, M., Sharik, T.L. 2022. Global assessment of forest education. Forestry Working Paper, 32, Food and Agriculture Organization of the United Nations.

Su, R., Rounds, J., Armstrong, P.I. 2009. Men and things, women and people: A meta-analysis of sex differences in interests. Psychological Bulletin, 135(6): 859.

UCTEA. 2023. Union of Chambers of Turkish Engineers and Architects. https://www.tmmob.org.tr/icerik/tmmobye-bagli-odalarin-uye-sayisi-660-bin-oldu (access date: 25.07.2025).

Yıldırımalp, S. 2021. Being a women engineer in Türkiye: A qualitative research on women forest engineers. Fırat University International Journal of Economics and Administrative Sciences, 5(1): 51-88. (in Turkish).

Yurdakul Erol, S. 2022. Comparison of forest engineering students’ attitudes towards their education and future jobs: Case results from Turkey. Sustainability, 14(1): 530.

Improving Forest Operation Efficiency: Insights from Japanese Case Studies and Applicability to Taiwan

Chieh Chih Liu[1]*, Yasushi Suzuki[2]

[1]Kochi University, Graduate School of Agriculture and Marine Science, Nankoku 783-8502, Japan
[2]Kochi University, Faculty of Agriculture and Marine Science, Nankoku 783-8502, Japan
*b24m6h12@s.kochi-u.ac.jp

Abstract

This study investigates strategies to boost the daily efficiency of integrated forest operations in Taiwan by drawing on Japanese expertise. Taiwan's forestry sector faces significant challenges, including a lack of modern machinery, high administrative costs, and difficult terrain, which severely impact operational efficiency and economic viability. Through on-site investigations at five Taiwanese logging sites, this research found that overall timber harvesting productivity, including transport to the sawmill, is roughly 2–4 m^3/person-day. This is considerably lower than the output from advanced, mechanized systems. The study also analyzes timber production methods and labor productivity in Kochi Prefecture, Japan, highlighting its strengths in mechanized slope operations, road network planning, and productivity optimization. The findings suggest that Taiwan's upstream operational and administrative inefficiencies directly undermine the profitability of downstream timber products. This preliminary report aims to provide a basis for future research and recommends that Taiwan adopt Japan's successful practices to help achieve its goal of increasing domestic timber self-sufficiency to 5% by 2030.

Keywords: *Forest operation efficiency, Taiwan forestry, Japanese forestry, Labor productivity, Timber self-sufficiency.*

1. INTRODUCTION

1.1 Background

According to 2023 statistics, Taiwan possesses abundant forest resources, with 2,197,090 hectares of forest despite a national land area of only 36,197 square kilometers (Liu, 2025). However, its forestry sector faces multiple challenges. These include stringent forestry policies, such as a ban on new forest road construction and limitations on clear-cutting areas, which contribute to a domestic timber self-sufficiency rate of only about 1%. The lack of adequate funding for maintaining existing harvesting roads also hinders efficient timber extraction.

Taiwan's forestry operations suffer from low efficiency due to a forest road network density of less than 1 m/ha (Liu, 2025) and a scarcity of modern harvesting machinery. The country's topography and climate, particularly the threat of typhoons like the one in 2009 (Typhoon Morakot), also pose significant risks and challenges to forest operations, highlighting the vulnerability of its mountainous regions.

Beyond physical and resource constraints, the administrative framework adds another layer of complexity. For example, felling permits require a three-month advance application. Pre-felling timber inventory is time-consuming, taking approximately 12 person-days per site, and manual log counting is required for verification during transport. These administrative burdens contribute significantly to high operational costs and low overall efficiency.

These upstream inefficiencies—stemming from a combination of mechanical, manual, and administrative issues—directly undermine the economic competitiveness of Taiwan's timber products in downstream processing and market sales. To achieve sustainable industry development, it is crucial to address the entire value chain.

1.2 Literature Review

Current forestry practices in Taiwan encounter significant bottlenecks in improving operational efficiency. High administrative costs (approximately 85 USD/m^3) (Liu, 2025), limited forest cloud information (currently only 20m DEM available), low road network density, and the scarcity of modern harvesting machinery all constrain the development of the forestry sector. These issues contribute to Taiwan's consistently low timber self-sufficiency rate, contrasting with its rich forest resources. In comparison, Japan has extensive experience in forest operation mechanization and efficiency enhancement, particularly in slope operations and timber production systems. Additionally, the importance of these systems is highlighted by the observation that in forestry, no two work sites have the same conditions, thus emphasizing the need to select the most suitable work system for each site to perform highly productive work (Minemoto, 2024). This requires managers to position machines and people to eliminate unnecessary movements and to identify and resolve bottlenecks in the harvesting process, such as the yarding stage in cable operations (Minemoto, 2024).

1.3 Research Objectives and Contributions

This study aims to propose improved strategies for Taiwan's forest operations by analyzing the current situation and drawing lessons from Japan's successful experiences in enhancing overall forest operation efficiency, encompassing felling, processing, yarding, and hauling activities. Specific objectives include:

1. To investigate and evaluate the comprehensive daily operational efficiency of existing logging sites in Taiwan, considering both operational and administrative factors.
2. To analyze the timber production systems and labor productivity calculation methods in Kochi Prefecture, Japan.
3. To compare operational models between Taiwan and Japan, providing concrete recommendations for improving Taiwan's forestry efficiency and enhancing the economic competitiveness of Taiwan's timber products throughout the value chain.

The contribution of this research lies in providing an empirical basis and policy recommendations for the sustainable development of Taiwan's forestry, particularly in increasing domestic timber self-sufficiency and addressing the challenges posed by severe natural environments.

2. MATERIAL AND METHODS

This study employs a comprehensive and multi-faceted approach to analyze the current state of forest operations in Taiwan and identify key areas for improvement. The methodology integrates quantitative analysis of field data with qualitative insights from expert interviews and a review of existing literature and regulatory frameworks. The ultimate goal is to provide a complete picture of the challenges facing Taiwan's forest industry and propose a clear path forward.

2.1 Research Methodology and Data Collection

This research combines both field-based data collection and comprehensive literature review to build a robust foundation for analysis. The key methods utilized are as follows:

- **Reference to Prior Research:** Detailed operational efficiency data for five representative logging sites in Taiwan, covering various methods and geographical conditions, were primarily referenced from the master's thesis by Tseng (2023). This foundational data provides a comprehensive overview of existing productivity levels across different working circles and harvesting techniques.
- **Time and Motion Studies through Video Analysis:** To obtain precise and objective data on the efficiency of various forest operations, video recordings were made of different work cycles (e.g., felling, yarding, processing, and loading). This method allows for detailed, frame-by-frame analysis of each task element, minimizing observer bias and enhancing data accuracy. The data collected includes:
    - **Work Cycle Components:** Detailed start and end times for each sub-task within a cycle (e.g., pulling a line, hooking, skidding, unhooking, and returning).
    - **Non-Productive Time:** Documentation of all non-work activities, such as equipment maintenance, discussions among workers, and delays due to external factors, which are crucial for calculating overall operational efficiency.
    - **Impact of Conditions:** Recording of environmental variables such as terrain steepness, log size, and weather conditions (e.g., rainfall) to analyze their influence on operational time.
- **Interviews with Industry and Government Professionals:** Semi-structured interviews were conducted with a broad range of stakeholders to gather qualitative and quantitative data that is not readily available in public records. Interviewees include:
    - **Government Officials:** Representatives from the Taiwan Forestry and Nature Conservation Agency (and its regional offices) to understand the administrative framework, such as the three-month advance permit application process, the requirements for detailed pre-felling timber inventories, and the procedures for log verification upon hauling.
    - **Academics and Scholars:** Experts in forest engineering and related fields to gain insights into theoretical models, data analysis techniques, and international best practices.
    - **Forestry Business Owners and Field Managers:** To gather firsthand knowledge on daily operational challenges, the actual costs of labor and machinery, and the practical impact of government regulations on their business and workflow.
- **Analysis of Historical and Logistical Data:**
    - **Company Records:** Analysis of daily work reports and logbooks from forestry companies to obtain historical data on production volumes, fuel consumption, and maintenance records.
    - **Environmental Data:** Integration of environmental data from sources like the Taiwan Central Weather Bureau and the Soil and Water Conservation Bureau to assess the impact of rainfall and soil conditions on forest operations and planning.

- **Cost Data:** Collection of specific cost data for machinery (purchase/lease and maintenance) and consumables (e.g., fuel and oil) in Taiwan to create a realistic economic model.

- **Comparative Analysis of Regulatory and Technical Frameworks:**
  - A comparative study was conducted to analyze the differences in forestry regulations and timber disposal regulations between Taiwan and Japan. This analysis highlights how different policy approaches affect the feasibility of modern, efficient logging practices.
  - Existing research and literature from Japan, with a particular focus on the timber production systems and technologies used in Kochi Prefecture, were reviewed to identify proven strategies that could be adapted for Taiwan's unique conditions.

The combination of these methods, including the detailed time analysis from video footage, will be used to provide a comprehensive and nuanced understanding of the current situation and the necessary improvements needed for Taiwan's forestry sector.

2.2 Analytical Methods

The collected data will be analyzed using a combination of forestry engineering and economic methods to derive comprehensive insights, focusing on the specific context of Taiwanese forest operations.

- **Time and Motion Analysis:**
  - Video recordings of logging operations will be analyzed frame-by-frame to obtain precise time measurements for each operational element within the work cycle (e.g., felling, yarding, and processing). The analysis will aim for a statistically significant sample of at least 30 to 50 complete work cycles for each distinct operational method (e.g., sled yarding, tower yarding, etc.) to ensure reliable results.
  - The collected time data will be correlated with variables such as slope, stand conditions (e.g., forest composition and soil type), and log size to identify key factors influencing operational duration and efficiency.
- **Labor Productivity Analysis:**
  - Thi s analysis is centered on the Labor Productivity Theorem, which evaluates the combined impact of different operational stages on overall productivity using the following formula:
    Q=q1 1 +q2 1 +q3 1 +⋯+qn 1 (1)
  - where Q represents the total productivity and qn represents the productivity of each individual stage. This model will be specifically adapted to account for the non-simultaneous nature of logging operations in Taiwan, such as the two-month period between felling and yarding.
- **Statistical Analysis:**
  - Statistical methods, such as regression analysis and analysis of variance (ANOVA), will be employed to quantify the relationships between various factors (e.g., rainfall, slope, road network density) and operational efficiency and costs. This approach will help identify critical variables affecting productivity and facilitate the creation of predictive models to estimate performance under different environmental and operational conditions.

- **Economic Performance and Breakeven Analysis:**
  - Using the cost data and productivity figures, a detailed economic analysis will be performed. This includes calculating the total cost per cubic meter of timber produced for each operational method.
  - A breakeven analysis will be conducted to determine the minimum productivity and timber selling price required for each operation to be financially viable, similar to the methodology presented in Suzuki et al. (2016). This will highlight the economic impact of operational and administrative inefficiencies.
- **Comparative Analysis:**
  - The findings from the Taiwanese logging sites will be compared with existing research and best practices from Japan (with a specific focus on the technologies and systems in the Kochi Prefecture) and Korea. The analysis will also highlight the differences in regulations, timber disposal laws, and technology adoption between Taiwan and Japan to identify feasible strategies for improving Taiwan's forestry.
  -

3. RESULTS AND DISCUSSION

3.1 Operational and Economic Performance

This section presents the results of the operational and economic analyses, which reflect the current productivity and cost structures of Taiwan's forest industry.

- **Overall Timber Harvesting Productivity and Cost:** The study reveals that the average daily productivity for integrated harvesting operations in Taiwan, including transportation to the sawmill, is approximately 2–4 m^3/person-day. The total cost of raw timber acquisition, including transportation to the sawmill, is estimated to be around 85 USD/m^3 (This study's observations and interviews). This figure is significantly lower than the productivity of advanced mechanized systems observed in other studies, such as the 10.2–12.5 m^3/PMH reported for tower yarders in South Korea (Baek et al., 2020).
- **Preliminary Case Study Observations (This Study's Observations and Interviews):** Initial observations and interviews conducted for this study provide specific insights into various logging operations in Taiwan. These preliminary data points highlight the diverse conditions and efficiency levels across different sites:

  - **Hushan (虎山) Forestry Ltd Site:**
    - **Location Information:** Elevation around 1,270 meters, Penglai Forest Road.（24°32'12.61"Ｎ, 121° 0'6.65"Ｅ）
    - **Forest Road Width:** 3.5m.
    - **Timber Volume:** ~500 m^3/ha.
    - **Operational Efficiency:** ~4 m^3/person-day (overall daily efficiency for the team, long-term average; team works ~6 hours/day).
    - **Logging Method:** Felling with chainsaws; skidding with a grapple-equipped excavator and winch (average yarding distance 100m, typical short-distance pull 30m); processing with chainsaws; loading with grapple-equipped excavator; transportation by truck.

Figure 1. Penglai

- **Hushan (虎山) Forestry Ltd Site:**
  - **Location Information:** Elevation around 1,300m, Ruisui Forest Road. （23°29'42.93"Ｎ, 121°16'49.80"Ｅ）
  - **Forest Road Width:** 3.5m.
  - **Forestry Mixture Rate:** Mixed coniferous and broadleaf forests with a broadleaf mixture rate of over 50%.
  - **Operational Efficiency:** ~4 m^3/person-day (overall daily efficiency for the team, long-term average; team works ~6 hours/day).
  - **Logging Method:** Felling with chainsaws; yarding with TST tower yarder (Avg. Yarding Distance 150m); processing with handheld chainsaws;
  - loading with grapple-equipped excavator; transportation by truck.

Figure 2. Ruisui

- **Zhengchang (正昌) Sawmill Co., Ltd. Site**
  - **Location Information:** Elevation around 1,123 meters, Luoshan Forest Road.（24°34'40.66"Ｎ, 121° 7'9.95"Ｅ）
  - **Forest Road Width:** 3.5m.
  - **Timber Volume:** ~350 m^3/ha.
  - **Operational Efficiency:** ~2.5 m^3/person-day (for yarding and processing).

Figure 3. Zhengchang

- **Felling Efficiency:** ~100 m^3/person-day (felling personnel relocate after felling; return after ~2 months of drying).
- **Logging Method:** Felling with chainsaws; sled yarder yarding (Avg. Yarding Distance 250m, 2.5 m^3/person-day); processing with handheld chainsaws; loading with grapple-equipped excavator; transportation by truck.
- **Road Network Density and Harvesting Method Correlation:** In areas with a road network density of less than 10 m/ha, sled yarding is employed, yielding an efficiency of approximately 2.5 m^3/person-day for yarding. Conversely, in areas with a road network density of approximately 80 m/ha, a 13-ton excavator paired with a single-drum winch can be utilized for harvesting, achieving an efficiency of approximately 10 m^3/person-day.

- **Cost Analysis:** The cost analysis shows that the high cost of raw timber acquisition, exacerbated by operational inefficiencies and administrative burdens, significantly impacts the economic viability of the entire forestry value chain. As demonstrated by Lee (2024), while downstream processing of products like dimensional lumber and essential oils can be profitable, the high upstream costs (e.g., (e.g., approximately 85USD/m^3 in administrative costs alone, a figure derived from **Zhengchang Sawmill Co., Ltd.**) often diminish these margins.

3.2 Key Findings and Discussion

The findings of this study point to a critical disconnect between the potential for profitable downstream processing and the high costs and low efficiency of upstream forest operations.

- **Impact of Administrative Frameworks:** The complex regulatory environment in Taiwan, characterized by mandatory pre-felling inventories and manual log verification, introduces substantial non-productive time and cost into the harvesting process. These administrative burdens, combined with the non-simultaneous nature of felling and yarding, create a unique and challenging operational environment.
- **Potential for Improvement:** Drawing on comparative analysis with Japanese and Korean systems, this study highlights several key areas for improvement in Taiwan's forestry:

- **Mechanization:** The adoption of modern, high-efficiency machinery like advanced tower yarders and processors, which are well-suited for Taiwan's steep terrain, could dramatically increase productivity.
- **Road Network Optimization:** A strategic focus on increasing forest road network density would enable the use of more efficient and cost-effective harvesting methods.
- **Process Streamlining:** By addressing the administrative bottlenecks and optimizing the workflow, Taiwan could reduce non-productive time and lower the overall cost of raw timber.

4. CONCLUSION AND SUGGESTIONS

This study, through a comprehensive analysis of the current state of forest operations in Taiwan, highlights the significant challenges and potential for improvement in the industry. Taiwan's low operational efficiency, exacerbated by a challenging physical environment and complex administrative framework, is a major impediment to the sustainable development of its forestry sector.

However, by drawing lessons from the experiences of advanced forestry nations like Japan and Korea, there is a clear path forward. Through the strategic introduction of appropriate machinery, the optimization of operational processes, and a commitment to streamlining administrative burdens, Taiwan can significantly improve its forest operation efficiency and reduce the overall cost of raw timber. This, in turn, will enhance the profitability and market competitiveness of its processed timber products and fostering a more robust and sustainable forest industry.

REFERENCES

Baek, S. A., Cho, K. H., & Lee, E. 2020. Performance comparison for two cable extraction machine in Larix Kaempferi(Lamb.) Carr. Plantation. *Sustainability*, 12.

Minemoto, I. 2024. Timber Production and Cost & Labor Productivity. Presentation, Kochi Prefectural Forest Technology Center and Kochi Forestry College.

Lee, B.-X. 2024. *Cost benefit analysis of production for plantation forests*. Master's Thesis, National Taiwan University, School of Forestry and Resource Conservation.

Liu, C. C. 2025. Improving Forest Operation Efficiency: Insights from Japanese Case Studies and Applicability to Taiwan. Oral Presentation, International Conference of KSFE-FETEC 2025.

Suzuki, Y., Yamasaki, S., Watanabe, N., Fukuda, Y. 2016. Productivity and cost efficiency of a cable logging operation at a clear cut broad-leaved forest stand to supply feedstock for woody biomass electric generation. *J. Jpn. For. Eng. Soc.*, 31(2): 85-91.

Tseng, K.-Y. 2023. *Yarding Productivity of Taiwan Coniferous Plantation Harvesting Operations*. Master Thesis, National Ilan University, Department of Forestry and Natural Resources.

Inoue, M., et al. 2001. *機械化のマネジメント* (Mechanization Management). Japan Forest Technology Association.

New Approaches in Forest Harvesting Operations in Türkiye

Abdullah E. Akay*, Serhat Akarsu, Teslime Nazilli

Forest Engineering Department, Faculty of Forestry, Bursa technical University, 16310 Bursa, Türkiye
*abdullah.akay@btu.edu.tr

Abstract

Forest areas in Türkiye are 23.4 million hectares, covering approximately 29.8% of the country's total area. Approximately 94.72% of the forests are operated as high forests and 5.28% as coppice forests. The wood-based forest products constitute the main source of economic gain from the forestry sector. In recent years, the use of advanced mechanized harvesting equipment in industrial forests has increased in order to meet the high volume wood raw material demands of companies producing wood-based panels. Therefore, harvesting equipment such as skidder, feller-buncher and harvester are used more widely. In mountainous regions, cable yarders have been effectively used by utilizing cable yarders (MOZ 300, 500GR), recently purchased by General Directorate of Forestry from Tajfun company. This paper aimed to describe the new approaches recently started to be implemented in forest harvesting operations in Türkiye. Besides, some suggestions have been provided to improve the proportion of using mechanization in forest operations.

Keywords: *Forestry sector, forest operations, mechanization, job certification.*

1. INTRODUCTION

In order to obtain optimum efficiency from forest resources, which are the leading natural resources, and to minimize environmental damage, economic, environmental and sustainable decisions should be taken in forestry activities (Kovácsová and Antalová, 2010). Considering that the demand for forest products will increase in the world, the use of modern techniques and technological tools, especially in the production of wood-based forest products, is of great importance.

Production of wood-based forest products consist of the stages of cutting and felling, delimbing, debarking, bucking, extracting from the harvesting unit, loading, hauling to depots, and unloading and stacking in the depots (Eker and Acar, 2006). These stages are carried out using different techniques and have continued their development from the beginning to the present day to perform the work economically, easily and quickly (Coşkun et al., 2010). On the other hand, forest harvesting activities that are not properly planned and organized can increase the cost and cause loss of time and economic value (Akay et al., 2007; Eroğlu, 2012).

The principle of sustainability should be taken into consideration during all forest harvesting activities in forests. However, since the collection of primary forest products scattered in the forest in a certain place is carried out under very difficult conditions, stand damages may occur. If forest harvesting activities are well planned and carried out carefully, standing trees, saplings, forest soil and primary forest products will be protected and the sustainability of forests can be ensured. To achieve this goal, the most appropriate harvesting methods and machines should be selected and implemented among many alternatives (Eroğlu, 2012).

The most difficult and costly stages in forest harvesting activities are cutting trees and extracting them from harvesting unit to the landing areas. In Türkiye, the cutting stage of trees is mostly carried out using a chainsaw, while the stage for extracting wood raw materials from the units is carried out using human-animal powered and partly machine powered methods. On the other hand, in recent years, mechanical harvesting methods have started to be preferred more frequently, especially in regions where intensive forestry is carried out (Akay et al., 2016). In addition, local organizations, which are among the top in Europe in the wood-based panel industry, supply a significant portion of their high-volume wood raw material demands from forest resources in Türkiye.

Supplier companies, which are responsible for continuously meeting these demands, are developing their machine parks and using mechanical systems intensively in order to produce wood raw materials in large forest areas in a short time. In this context, harvester, feller-buncher and skidder have taken their place among the modern mechanical production tools used in Türkiye (Akay et al., 2017). The use of cable yarders in extraction of forest products from the units, especially in the forest areas spreading in mountainous terrains with steep slopes, provides an effective and economical results (Erdaş, 2008). Cable yarders with different models and features have been used in Türkiye for many years. These include Koller, Urus, Wyssen, Baco, Hinteregger and Gartner brand yarders. Recently, Moz brand, coming with short and medium distance yarding options, have been started to be used in mountainous areas. In this paper, it was aimed to present the new machines used in mechanized harvesting operations in Türkiye. Moreover, some suggestions were provided to increase the benefits of using mechanization in forest operations.

2. HARVESTING PRACTICES

2.1. Harvester Operations

Bilici et al. (2017) investigated the productivity of Doosan DX 300lC model harvester in a clear cut operation in a Brutian pine stand located in Bursa Osmangazi Forest Enterprise Directorate (Figure 1). The basic factors affecting the productivity were determined based on time and motion study. The harvesting activity begins with the harvester moving to the next tree to be cut after the previous trip is completed.

Figure 1. Doosan DX 300lC harvester (Bilici et al., 2017)

The first work stage is completed when the harvester reaches the tree to be cut. The second work stage covers the time spent by the harvester to grab the tree with the cutting-head and cut it. The third work stage covers the time when the cutter head is used for process operations consisting of delimbing, topping and bucking.

The results showed that the harvester's efficiency was 23.91 m^3/h. It was determined that the harvester's efficiency was mainly affected by the tree size and directly affected the total processing time of the trees cut in the study area. The results indicated that that the most time-consuming stage was processing stage, followed by grapping and cutting. It was also found that there was a significant relationship between tree volume and harvester productivity.

2.2. Feller-buncher Operations

Gülci et al. (2021) investigated the productivity of a Wood Cracker C450 model feller-buncher in a Maritime pine stand located in Lapseki province of Çanakkale in north-west part of Türkiye (Figure 2). The time and motion study was implemented to estimate the productivity of a whole-tree harvesting operation. The effects of the stand parameters including tree height, DBH, and volume on productivity were investigated using statistical analysis. The work stages measured in the study included moving to designated tree, cutting the tree at the stump, and bunching the tree at the skid trail. The results indicated that the average productivity of the feller-buncher was 75 m^3/hour. It was found that the most time-consuming work element was moving to the tree, followed by cutting the tree. Statistical analysis showed that productivity of the feller-buncher varies with the tree height, DBH, and volume.

Figure 2. Wood Cracker C450 model feller-buncher

2.3. Skidder Operations

Akay et al. (2016) evaluated the performance of the Tigercat 635D skidder in terms of productivity during clear cut operations in Brutian pine stands located in Çanakkale Forest Enterprise Directorate. In the field studies, productivity was determined based on time and motion study and main parameters that affect productivity were investigated. These parameters included skidding distance, ground slope, timber volume, and number of logs per turn.

The work stages included moving unloaded, grapping loads, and skidding loaded while unloading time included into skidding time as it was insignificant time. The results indicated that average productivity was 104.50 m^3/hr. It was found that the main factor affected the skidder performance was skidding distance, which was followed by timber volume.

Figure 3. Tigercat 635D model skidder (Akay et al., 2016)

2.4. Cable Yarder Operations using MOZ 500

Büyüksakallı (2024) evaluated the productivity of Moz 500GR model cable yarder during a harvesting study conducted in Köyceğiş Forest Enterprise Directorate (Figure 4). In the application, the cable yarder power was provided from the tail shaft of the Tümason 8105 model farm tractor. In the time measurement, field videos were recorded using the "DJI Mavic Pro" UAV and the time values of the work stages were determined on the computer screen. The work stages that took place during the operation were given below:

- Reaching the loading point of the wagon
- Lowering the connecting cable to the loading point
- Pulling and connecting the cable to the product
- Pulling the connected product to the wagon
- Reaching the loaded wagon to the ramp
- Lowering the product to the ground
- Unwinding the product from the cable
- Pulling the empty cable to the wagon

Figure 4. Mozz 500GR model cable yarer

The parameters affecting the productivity of the cable yarder taken into account were average product length, average product diameter, lateral yarding distance, number of pieces and total product volume. The results indicated that the average productivity of the cable yarder was 11.76 m^3/hour. It was determined that there was a positive relationship ($p<0.001$) between product diameter, product length and product volume and yield at the 99% confidence level. The most time consuming work stage was pulling and connecting the cable to the product, followed by the loaded wagon reaching the landing.

3. CONCLUSION AND SUGGESTIONS

Mechanical harvesting vehicles have high hourly unit costs due to their high purchase prices and high fuel prices in Türkiye (Bilici et al., 2018). In addition, deformation occurs in the forest soil as a result of deep rut depths and compaction caused by heavy equipment (Grace et al., 2006). Therefore, in order to benefit from the advantages of modern mechanized harvesting equipment, mechanized harvesting systems should be planned by taking into account productivity and environmental factors and the most suitable vehicle should be selected for the purpose. However, there is few scientific study or research that deals with the productivity and environmental effects of the mechanized harvesting equipment that have been recently used in Türkiye. In order to reveal the performance of the harvesting equipment, productivity analyses of these vehicles should be carried out and their environmental effects should be also studied. Besides, the machine operators should receive appropriate technical education and practical training in the field to increase productivity. Besides, social conditions of the operators should be improved in order to increase their motivation and work related stresses.

REFERENCES

Akay, A.E., Sessions, J., Aruga, K. 2007. Designing a forwarder operation considering tolerable soil disturbance and minimum total cost, Journal of Terramechanics. 44(2): 187-195.

Akay, A.E., Özkan, D., Bilici, E. 2016. Assessing productivity and work safety of a mechanized logging operation, The International Forestry Symposium (IFS 2016), 7-11 December. Kastamonu, Turkey.

Akay, A.E., Bilici, E., Taş, İ., Özkan, D. 2017. Türkiye ormancılığında mekanik üretim araçlarının kullanımı: Çanakkale örneği, IV. Ulusal Ormancılık Kongresi, 14-15 Kasım. Antalya, Türkiye.

Bilici, E., Akay, A.E., Abbas, D. 2017. An evaluation of a fully mechanized forest harvesting operation in Bursa, Turkey, ISFOR 2017 International Symposium on New Horizons in Forestry, 18-20 October. Isparta, Turkey.

Büyüksakallı, H. 2023. Using Digital Images Obtained from an Unmanned Aerial Vehicle for Evaluating Productivity and Soil Deformation of Mechanized Harvesting Equipment, Ph.D. Thesis, Bursa Technical University, Bursa.

Coşkun, K., Eroğlu, H., Özkaya, M.S., Çetiner, K., Bilgin, F. 2010. An assessment in terms of mechanization of timber harvesting operations in Artvin Forest Regional Directorate, III National Blacksea Forestry Congress, 20-22 may, Artvin, Türkiye.

Eker, M., Acar, H.H. 2006. Development of annual operational planning model for timber harvesting, Süleyman Demirel University Journal of Natural and Applied Sciences. 10(2): 235-248.

Erdaş, O. 2008. Transportation Techniques. KSÜ, Kahramanmaraş, 130/20, 554 p.

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.

Gülci, N., Yüksel, K., Gülci, S., Serin, H., Bilici, E., Akay, A.E. 2021. Analysis of a feller-buncher productivity: a case study of whole-tree harvesting from Marmara region, Turkey. Annals of Forest Research. 64(1):99-110.

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

Enhancing Forest Surveillance in The Thailand - Myanmar Border Using Iot - Based Camera Traps

Chakrit Na Takuathung[1]*, Yongyut Trisurat[2], Jenjira Fungjanthuek[2], Sitthichai Jinamoy[3]

[1]Department of Forest Engineering, Faculty of Forestry, Kasetsart University, Bangkok, Thailand
[2]Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand
[3]Thailand Hornbill Research Foundation, Bangkok, Thailand
*chakrit.n@ku.ac.th

Abstract

The intensifying conflict in Myanmar has led to increasing displacement into Thailand, placing greater pressure on forest resources along the border. This study evaluated the application of Internet of Things (IoT) technology for forest monitoring in community forests and national reserved forest in Mae Hong Son Province, along the Thailand–Myanmar border. Three Spartan 4G camera traps were installed at each site to capture images and videos of moving objects, with real-time data transmission to a server and mobile application. Data were collected continuously over four months and analyzed using descriptive statistics. The cameras achieved a 100% operational rate, and 35% of the 6,385 images captured showed detectable objects. Salawin National Reserved Forest recorded the highest number of human detections and weapon sightings compared to smaller community forests. Non-timber forest product collection events were more frequent in the reserved forest, while wildlife detections were more common in certain community forests. A negative relationship between weapon detections and wildlife presence was observed. These findings demonstrate that IoT-based camera traps are effective for real-time monitoring and can enhance forest protection strategies in conflict-affected border regions.

Keywords: *Forest Monitoring, Internet of Things (IoT), Camera traps.*

1. INTRODUCTION

The Thailand–Myanmar border is part of the Indo-Burma biodiversity hotspot, a region noted for high endemism and species richness under increasing anthropogenic pressure (Hughes, 2017). The forests of Mae Hong Son Province provide habitat for threatened species such as the Asiatic jackal (*Canis aureus*) and leopard cat (*Prionailurus bengalensis*), along with diverse bird and reptile assemblages (Chutipong et al., 2014). Since the military coup in Myanmar in February 2021, escalating conflict has displaced over 1.7 million people internally, with thousands seeking refuge in Thailand (United Nations High Commissioner for Refugees, 2023). Many displaced people rely on forest resources for subsistence—collecting fuelwood, hunting, and harvesting NTFPs—which can lead to accelerated resource depletion when population influxes are sudden and unregulated.

Law enforcement in border forests faces significant challenges, including porous frontiers, safety risks to rangers, and logistical constraints that limit patrol frequency (Critchlow et al., 2017). Optimized patrol allocation and the use of patrol data can increase illegal-activity detections without additional resources. Community-based forest management can also yield environmental and social benefits, reducing deforestation while improving livelihoods (Bowler et al., 2012; Rasolofoson et al., 2015; Oldekop et al., 2019).

The IoT—networks of connected devices with sensors, processing, and communication capabilities—offers opportunities for near-real-time conservation monitoring (Gubbi et al., 2013). In ecology, IoT has been used for automated acoustic biodiversity monitoring (Aide et al., 2013), GPS telemetry for tracking animal movements (Hebblewhite & Haydon, 2010 , and camera-trap networks that can accelerate conservation responses. Ahumada et al. (2020) highlight that rapid processing of camera-trap data—especially via AI-assisted classification tools—can significantly accelerate conservation monitoring responses, even if they stop short of delivering real-time detection of illegal activity. Camera traps are widely used in wildlife research to detect elusive or nocturnal animals (O'Connell et al., 2011). Integration of 4G cellular modules allows images and videos to be transmitted instantly to servers, reducing the need for field retrieval and enabling rapid threat responses (Steenweg et al. 2017; Gubbi et al. 2013). Such systems have been effective in detecting illegal activities in Africa (Critchlow et al. 2017) and supporting flagship species conservation in Southeast Asia (Rayan & Linkie, 2016). IoT-enabled camera networks also help monitor human–wildlife conflict (Meek et al., 2015), and advances in machine learning are improving their ability to automatically detect species and human threats (Doull et al. 2021).

Despite these advances, politically sensitive, transboundary forests remain under-studied. This research evaluates the operational reliability, detection efficiency, and conservation potential of IoT-based camera traps deployed in both community-managed and state-managed forests along the Thailand–Myanmar border.

2. MATERIAL AND METHODS

The study was conducted in Mae Hong Son Province, northern Thailand, which shares a rugged, forested border with Myanmar. This province is characterized by steep mountainous terrain, elevations ranging from 200–1,900 meters above sea level, and a tropical monsoon climate with distinct wet (May–October) and dry (November–April) seasons. The region contains a mosaic of forest types, including mixed deciduous forest, dry dipterocarp forest, and hill evergreen forest.

Five forest sites were selected: four community forests—Luek (LEKCF), Pratoomuang (PTMCF), Thungphaman (THPCF), and Top (TOPCF)—and one national reserved forest, Salawin (SALRF). Community forests are managed under Thailand's Community Forest Act, which grants local committees authority to regulate resource use and organize patrols, while the national reserved forest is managed by the Royal Forest Department with limited local participation. Sites were chosen based on their proximity to border crossings, and refugee camps (Figure 1).

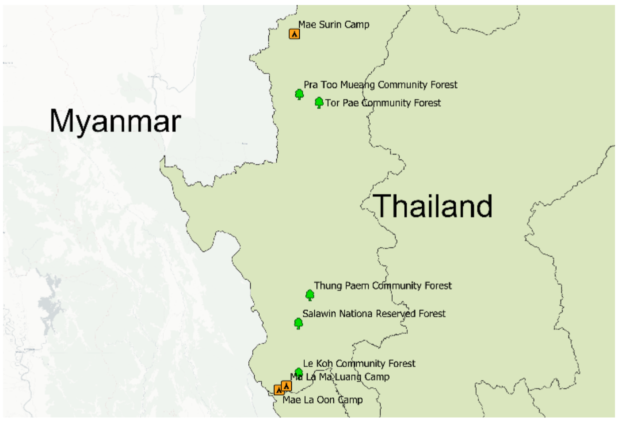


Figure 1. The study sites in Mae hong son province, Thailand

2.1 Camera Trap Deployment

A total of fifteen Spartan 4G LTE camera traps were deployed, three per site. Camera locations were selected in consultation with local rangers and community members, focusing on entry points used by villagers, and areas identified as high-risk for poaching or illegal logging. The GPS coordinates of each location were recorded.

Cameras were mounted on trees at heights of 9-10 meters above ground to hide from humans. Devices were angled to minimize false triggers from vegetation movement and set to motion-activated mode. Each detection event recorded a 20-second HD video and a still image, both transmitted via the 4G network to the Spartan management platform. Power was supplied by lithium AA batteries to ensure extended operation.

2.2 Data Retrieval and Processing

Images and videos were transmitted in near-real time to the Spartan online portal, accessible by authorized researchers and enforcement officers. This remote retrieval reduced the need for frequent site visits, minimizing disturbance and security risks in politically sensitive areas.

2.3 Image Classification

All media files were manually reviewed by trained observers. For each detection event, the following metadata were recorded:

- Date and time stamp
- Site and camera ID
- Object type (human, wildlife, vehicle, other)
- Wildlife species identification (where possible)
- Human category (ranger, villager, unknown)
- Presence of weapons or harvesting tools
- Observable activity (e.g., walking, carrying bundles, riding a motorcycle)

2.4 Statistical Analysis

Detection rates were calculated as the proportion of images containing identifiable objects relative to the total number of images captured. Temporal activity patterns were summarized by aggregating detections into hourly bins for humans, then visualized as activity curves. Pearson’s correlation coefficient was used to assess the relationship between weapon detections and wildlife sightings per site. Spatial comparisons between community and reserved forests were made using relative detection rates for each object category. Data processing and statistical analyses were conducted in R and Microsoft Excel.

3. RESULTS AND DISCUSSION

During the four-month deployment, all 15 Spartan 4G LTE camera traps operated without technical failure, yielding a 100% operational rate. Across all sites, 6,385 images were captured, of which 2,262 (35%) contained identifiable objects (Table 1). Detection rates varied among sites: Salawin National Reserved Forest (SALRF) had the highest rate (64%), followed by Pratoomuang Community Forest (PTMCF) at 35% and Thungphaman Community Forest (THPCF) at 30% (Figure 2).

Table 1. Summary of camera trap deployment and detections by site

Site	Forest Type	No. of Cameras	Images Captured	Object Detections (%)
LEKCF	Community Forest	3	1,001	12
PTMCF	Community Forest	3	1,073	35
THPCF	Community Forest	3	1,068	30
TOPCF	Community Forest	3	1,313	16
SALRF	Reserved Forest	3	1,930	64

Figure 2. Detection rate (%) by camera site

The higher detection rate in SALRF is likely linked to its greater size and accessibility, which expose it to higher levels of human activity. Larger protected areas in tropical regions often face patrol coverage challenges due to limited ranger numbers relative to area size, making illegal entry and resource extraction less risky for offenders (Critchlow et al., 2017). In contrast, smaller community forests allow for more consistent surveillance by local patrols, which can deter illegal activities through social accountability and quicker response (Bowler et al., 2012; Rasolofoson et al., 2015).

Object detection rates can also reflect the efficiency of camera placement. Non-target triggers—such as vegetation movement or high light contrast—can produce false detections, inflating image volumes and consuming storage and processing resources. Where false detection rates are high, repositioning or re-angling cameras can reduce error and improve data quality (Meek et al., 2015; Steenweg et al. 2017).

Temporal activity analysis showed that human movement peaked between 06:00–20:00 (Figure 3), aligning with previous studies on subsistence and illegal forest use in Southeast Asia (Meek et al., 2015). This daytime activity pattern is consistent with daily work cycles, market trips, and NTFP collection schedules observed in rural forest-dependent communities. Wildlife activity, including *Prionailurus bengalensis*, *Canis aureus*, and *Muntiacus feae*, was sighted at nighttime (22:00–02:00) periods, suggesting temporal avoidance of humans—a behavioral adaptation documented in hunted tropical forest species (Harrison et al., 2016).

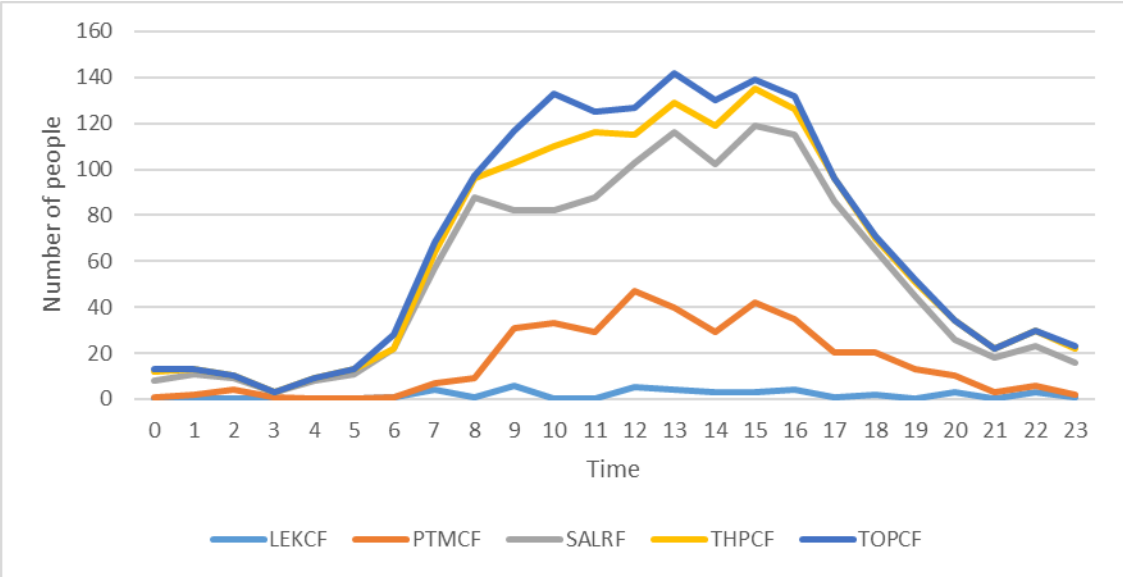


Figure 3. Hourly human activity pattern by site

Figure 4 illustrates the distribution of detected object types across the five study sites, with humans comprising the majority of detections, followed by livestock and wildlife. The dominance of human detections reflects the high level of forest use in both community-managed and reserved areas, consistent with other studies in Southeast Asia showing human presence as the most common trigger in multi-use forest landscapes (Steenweg et al. 2017). Livestock detections were especially prominent in community forests, indicating grazing as part of traditional land-use systems. While some grazing can be compatible with forest conservation, unmanaged or high-intensity grazing may lead to competition with wild herbivores and alter vegetation structure (Mishra et al., 2004). In contrast, wildlife detections were proportionally lower in SALRF, where frequent human and livestock activity likely reduces wildlife presence through disturbance or displacement (Harrison et al., 2016). The relatively higher proportion of wildlife detections in some community forests suggests that lower disturbance levels, coupled with active local oversight, can support species persistence even in human-modified landscapes (Rasolofoson et al., 2015).

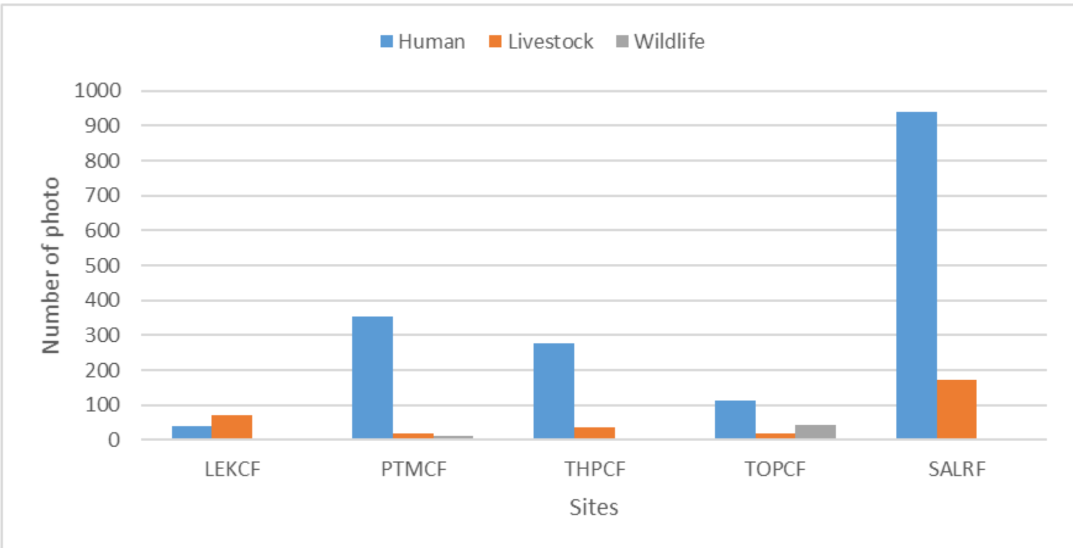


Figure 4. Object types detected by sites

Weapons were recorded in 53 events in SALRF and 50 in PTMCF (Figure 5). The negative correlation between weapon detections and wildlife sightings (Pearson's r = –0.43) supports research linking hunting pressure to reduced wildlife abundance (Harrison et al., 2016). Comparable IoT-based monitoring projects have reported similar patterns, where real-time detection of armed individuals facilitated faster enforcement responses (Ahumada et al. 2020; Critchlow et al. 2017).

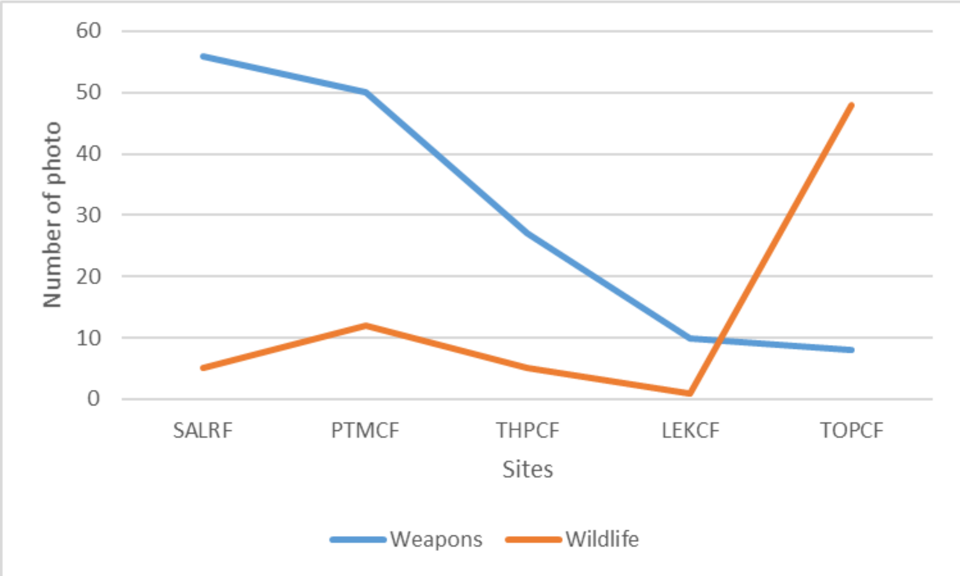


Figure 5. Comparison of weapon detections and wildlife sightings by site

NTFP harvesting events were more frequent in SALRF (79) than in THPCF (35), with bamboo the most collected resource. Such extraction pressure, especially in large state-managed reserves with low patrol coverage, has been documented in regions where community oversight is weak and enforcement is limited (Oldekop et al., 2019; Rasolofoson et al., 2015).

From a management perspective, concentrating patrols during identified peak human activity hours could improve deterrence, while maintaining nocturnal monitoring ensures wildlife data collection. Integrating IoT camera traps with GIS-based hotspot mapping and predictive patrol planning can further optimize ranger deployment (Critchlow et al., 2017). In politically unstable areas, these devices also act as low-risk observation points, reducing ranger exposure to danger while maintaining surveillance capability (Gubbi et al., 2013).

Finally, while the current study demonstrates the technical feasibility and conservation value of IoT camera traps, limitations include false triggers, the short monitoring period, and reliance on manual image classification. Incorporating machine learning-based image recognition could reduce processing time and enable rapid alerts, improving real-time intervention capacity (Doull et al. 2021).

5. CONCLUSION AND SUGGESTIONS

IoT-enabled camera traps demonstrated high operational reliability and provided continuous monitoring in remote forest sites along the Thailand–Myanmar border. The technology enabled the detection of both human and wildlife activity, revealing temporal patterns that can guide more efficient law enforcement deployment. Weapon detections were negatively correlated with wildlife presence, underscoring the impact of hunting pressure on biodiversity in the region.

Compared with large, centrally managed reserves, community-managed forests showed lower weapon detections and higher wildlife sightings, aligning with studies on the benefits of localized governance for conservation outcomes (Bowler et al., 2012; Oldekop et al., 2019; Rasolofoson et al., 2015). Integrating IoT surveillance with targeted patrols, real-time alert systems, and community engagement could strengthen conservation strategies in politically sensitive border zones.

Future work should explore integrating automated species and object recognition to reduce processing time and expanding deployments to additional border forests. Given the combined conservation and security challenges in the region, scaling up such technology could significantly improve biodiversity protection and resource management.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by the International Tropical Timber Organization (ITTO).

REFERENCES

Aide, T.M., Corrada-Bravo, C., Campos-Cerqueira, M., Milan, C., Vega, G., Alvarez, R. 2013. Real-time bioacoustics monitoring and automated species identification. PeerJ. 1: e103. https://doi.org/10.7717/peerj.103

Bowler, D.E., Buyung-Ali, L., Healey, J.R., Jones, J.P.G., Knight, T.M., Pullin, A.S. 2012. Does community forest management provide global environmental benefits and improve local welfare? Frontiers in Ecology and the Environment. 10(1): 29-36. https://doi.org/10.1890/110040

Chutipong, W., Lynam, A.J., Steinmetz, R., Savini, T., Gale, G.A. 2014. Sampling mammalian carnivores in western Thailand: Issues of rarity and detectability. Raffles Bulletin of Zoology. 62: 521-535.

Critchlow, R., Plumptre, A.J., Alidria, B., Nsubuga, M., Driciru, M., Rwetsiba, A., Beale, C.M. 2017. Improving law-enforcement effectiveness and efficiency in protected areas using ranger-collected data. Conservation Letters. 10(5): 572-580. https://doi.org/10.1111/conl.12288

Doull, K.E., Chalmers, C., Fergus, P., Longmore, S.N., Piel, A.K., Wich, S.A. 2021. An evaluation of the factors affecting "poacher" detection with drones, and the efficacy of machine-learning for detection. Sensors. 21(12): 4074. https://doi.org/10.3390/s21124074

Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M. 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems. 29(7): 1645-1660. https://doi.org/10.1016/j.future.2013.01.010

Harrison, R.D., Sreekar, R., Brodie, J.F., Brook, S., Luskin, M., O'Kelly, H., Rao, M., Scheffers, B., Velho, N. 2016. Impacts of hunting on tropical forests in Southeast Asia. Conservation Biology, 30: 972-981. https://doi.org/10.1111/cobi.12785

Hebblewhite, M., Haydon, D.T. 2010. Distinguishing technology from biology: A critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society B. 365(1550): 2303-2312. https://doi.org/10.1098/rstb.2010.0087

Hughes, A.C. 2017. Understanding the drivers of Southeast Asian biodiversity loss. Ecosphere. 8(1): e01624. https://doi.org/10.1002/ecs2.1624

Meek, P.D., Ballard, G., Fleming, P.J.S. 2015. The pitfalls of wildlife camera trapping as a survey tool in Australia. Australian Mammalogy. 37(1): 13-22. https://doi.org/10.1071/AM14023

Mishra, C., Van Wieren, S.E., Ketner, P., Heitkönig, I.M.A., Prins, H.H.T. 2004. Competition between domestic livestock and wild bharal Pseudois nayaur in the Indian Trans-Himalaya. Journal of Applied Ecology. 41(2): 344-354. https://doi.org/10.1111/j.0021-8901.2004.00885.x

O'Connell, A.F., Nichols, J.D., Karanth, K.U. 2011. Camera traps in animal ecology: Methods and analyses. Springer, Tokyo. 271 p. https://doi.org/10.1007/978-4-431-99495-4

Oldekop, J.A., Sims, K.R.E., Karna, B.K., Whittingham, M.J., Agrawal, A. 2019. Reductions in deforestation and poverty from decentralized forest management in Nepal. Nature Sustainability. 2(5): 421-428. https://doi.org/10.1038/s41893-019-0277-3

Rasolofoson, R.A., Ferraro, P.J., Jenkins, C.N., Jones, J.P.G. 2015. Effectiveness of community forest management at reducing deforestation in Madagascar. Biological Conservation. 184: 271-277. https://doi.org/10.1016/j.biocon.2015.01.027

Rayan, D.M., Linkie, M. 2016. Managing conservation flagship species in competition: Tiger, leopard and dhole in Malaysia. Biological Conservation. 199: 114-124. https://doi.org/10.1016/j.biocon.2016.11.009

Steenweg, R., Hebblewhite, M., Kays, R., Ahumada, J., Fisher, J.T., Burton, C., Townsend, S.E., Carbone, C., Rowcliffe, J.M., Whittington, J., Brodie, J., Royle, J.A., Clevenger, A.P. 2017. Scaling-up camera traps: Monitoring the planet's biodiversity with networks of remote sensors. Frontiers in Ecology and the Environment. 15(1): 26-34. https://doi.org/10.1002/fee.1448

United Nations High Commissioner for Refugees (UNHCR). 2023. Myanmar displacement overview. UNHCR Situation Report. https://data.unhcr.org/en/country/mmr

Determination of Soil Losses in Narlıdere Watershed Using the RUSLE Method

Ömer Faruk Karan*, Esin Erdoğan Yüksel

Forestry Engineering Department, Forestry Faculty, Bursa Technical University, Bursa, Türkiye.
*omer.karan@btu.edu.tr

Abstract

This study aims to estimate annual soil loss and map potential erosion risk in the Narlıdere Watershed located in the Kestel district of Bursa province using the Revised Universal Soil Loss Equation (RUSLE) model with remote sensing and Geographic Information Systems (GIS). Numerical data were analyzed using the rainfall erosivity (R), soil erosion capability (K), topography and slope (LS), vegetation cover (C) and support practices (P) parameters included in the RUSLE model in a GIS environment. According to 21-year precipitation data (2000 - 2021) obtained from the Kestel meteorological station, the average annual precipitation was calculated as 716.8 mm. The R factor value, which is one of the RUSLE model parameters, varies between 671.75 and 1014.89 MJ. mm. ha/h/year. The K factor value includes two different geological features. Of these, the values ranged from 0.014 for Calcic Cambisol (BK) and 0.022 for Eutric Cambisol (BE). The LS factor value was set between 0 and 726.75, the C factor value between 0 and 0.07, and the P factor was set at 1 due to the lack of any soil conservation measures in the basin. The study findings indicate that erosion in the Narlıdere Basin is particularly aggravated by steep slopes, insufficient vegetation, and unsustainable agricultural practices, and that this is one of the main causes of soil loss in the basin. The results demonstrate the urgent need to implement effective and targeted soil conservation strategies in high-risk areas. Such measures not only contribute to the preservation of soil structure but also play a critical role in the sustainable management of water resources and the preservation of the ecological balance in the basin. Therefore, planned and integrated soil conservation practices are crucial for preventing erosion and ensuring the sustainable use of natural resources.

Keywords: *Soil Erosion; RUSLE; GIS; Narlıdere watershed.*

1. INTRODUCTION

Soil erosion is exacerbated by global climate change and increased human activity, posing serious threats to agricultural productivity, ecosystem balance, and the sustainable management of natural resources. Inadequate soil and water conservation measures accelerate soil degradation, disrupt hydrological cycles, and reduce the quality and productivity of agricultural products. Erosion rates are influenced by numerous factors, including precipitation and wind, as well as land cover and land use characteristics. These interactions can significantly alter the severity of soil loss. While the average annual soil loss worldwide is 12–15 t/ha, this value in Turkey is estimated at 8.24 t/ha/year (Ganasri and Ramesh, 2016; Teng et al., 2016; Robinson et al., 2017; Aksoy and Kavvas, 2005; Panagos et al., 2015; Erpul et al., 2020).

In order to reduce soil loss and control erosion, various engineering and land management practices such as terracing, afforestation, and vegetative buffer strips are widely implemented. These practices effectively reduce runoff and erosion severity, while also contributing to improving water quality and protecting watershed ecosystems (Avcı et al., 2023; Huang and Liu, 2023; Shah and Dahal, 2023; Bai et al., 2023; Chiang et al., 2023; Shan et al., 2023; Olivier et al., 2023). Since monitoring studies based on field measurements are both costly and time-consuming, various models have been developed to estimate erosion risk. One of the most widely and effectively used of these models is the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978; Renard et al., 1997; Ghosal and Bhattacharya, 2020). In this study, the RUSLE model was integrated with Geographic Information Systems (GIS) to estimate annual soil loss in the Narlıdere Basin, Bursa, and to map the severity and distribution of erosion in the basin. The findings highlight the importance of effective soil conservation strategies, particularly in erosion-prone areas, and provide a scientific basis for management planning in regions with similar environmental and land-use conditions (Zerihun et al., 2018; Özcan et al., 2008).

2. MATERIAL AND METHODS

2.1. Study Area

Located within the boundaries of the Kestel district of Bursa province, the Narlıdere Basin has an elevation ranging from 142 to 820 meters and covers a large area of approximately 3,189.22 hectares. The basin's topography, due to its different elevations and slope variations, exhibits significant diversity in terms of natural water flow and soil properties. According to data obtained from the Kestel meteorological station, the basin receives an average annual precipitation of 716.88 mm and an average temperature of 15.5 °C (Yüksel and Karan, 2024). These climatic and topographic features are of critical importance in terms of soil erosion and water resources management in the basin.

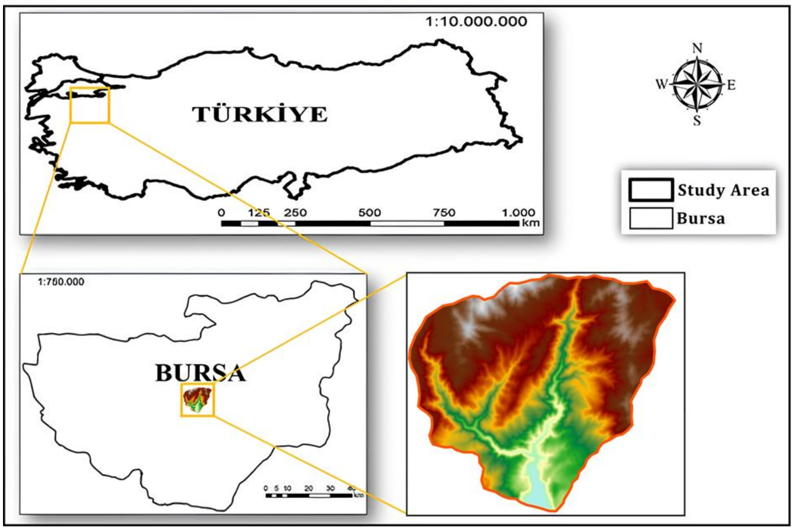


Figure 1. Geographic location of the Narlıdere Watershed

2.2. Data and Methodology

The RUSLE model is widely preferred worldwide due to its applicability in areas with data deficiency, low cost, and ease of use (Aksoy and Kavvas, 2005; Issaka and Ashraf, 2017; Zerihun et al., 2018). In this study, five basic factors of the model were used to determine soil loss in the Narlıdere Basin. The R factor, representing the precipitation erosion power, was calculated using 21-year (2000–2021) precipitation data obtained from the Kestel meteorological station. The K factor, indicating the soil erosion resistance, was determined based on geological maps of the region, and the LS factor, reflecting topographic factors, was obtained from isohypse data. The C factor, which represents vegetation cover and land use, was based on forest management and land use data and takes values between 0 and 1 as a parameter that has a direct impact on soil loss (Renard et al., 1991; Renard et al., 1997; Mukharamova et al., 2021). In addition, the P factor was accepted as 1 due to the absence of any soil protection or erosion control practices in the basin (Ebabu et al., 2022; Renard et al., 1997; Panagos et al., 2015a, 2015b; Schmidt et al., 2018). This approach allows for a clearer assessment of the existing erosion risk in the basin and the development of sustainable soil management strategies.

2.3. RUSLE Models Description

RUSLE is an empirical model employed to estimate the annual average soil loss for each pixel (Shaikh et al., 2020). It is regarded as one of the most widely applied models because of its efficiency and suitability for integration within Geographic Information Systems (GIS) (Ranzi et al., 2012; Delgado et al., 2022). Such advancements facilitate the generation of spatially explicit maps for each of the RUSLE factors, thereby enabling the identification and mapping of areas most vulnerable to severe erosion based on the following equation:

$$A = R \times K \times LS \times C \times P \quad (1)$$

In Equation 1, A denotes the annual average soil loss in the basin (t/ha/year). The R factor represents rainfall erosivity, the K factor indicates soil erodibility, the LS factor accounts for topography and slope length–steepness, the C factor reflects vegetation cover, and the P factor represents conservation support practices.

2.3.1. Precipitation erosivity (R)

The R factor in the RUSLE model is a key parameter that determines the potential amount of erosion that precipitation can cause on soil (Chen et al., 2010). This factor plays a critical role in estimating soil loss because the amount and intensity of precipitation directly affect the erosion rate. The R factor is usually calculated by considering the total precipitation amount and the kinetic energy of the precipitation (Beskow et al., 2009). In the RUSLE model, this effect is expressed as the EI value, which is calculated as the product of the kinetic energy of the precipitation and its maximum 30-minute intensity (Cürebal and Ekinci, 2006; Chen et al., 2010). However, in some cases, detailed precipitation data may not be available. In such data-deficient scenarios, the R factor can also be estimated using alternative methods such as annual mean precipitation or the Modified Fournier Index (MFI) (Arnoldus, 1977; Renard and Freimund, 1994; Yu and Rosewell, 1996). The Modified Fournier Index is considered a practical and reliable method for estimating erosion potential, particularly by evaluating rainfall data recorded over many years. In this study, the MFI method was used to determine the R factor for the Narlıdere Basin. This approach allows for accurate erosion risk assessment and mapping based on annual rainfall data in the region. Accurately determining the R factor is crucial for planning soil conservation strategies and sustainable land management.

$$MFI = \sum pi^2 / P_j \quad (2)$$

According to Equation 2, pi represents the monthly precipitation amount (mm), and Pj represents the annual precipitation average (mm). The R factor was calculated with the MFI-based formula R = (4.17 × MFI) − 152 (Cürebal and Ekinci, 2006). 21-year (2000–2021) records of Kestel Meteorological Station were used as precipitation data (Yüksel and Karan, 2024). The effect of elevation differences on precipitation was calculated with the formula Ph = Po + 54h, and this formula was based on the Schreiber method (Ardel, 1969; Dönmez, 1979). The R factor values vary between 671.7 and 1015 (Figure 2).

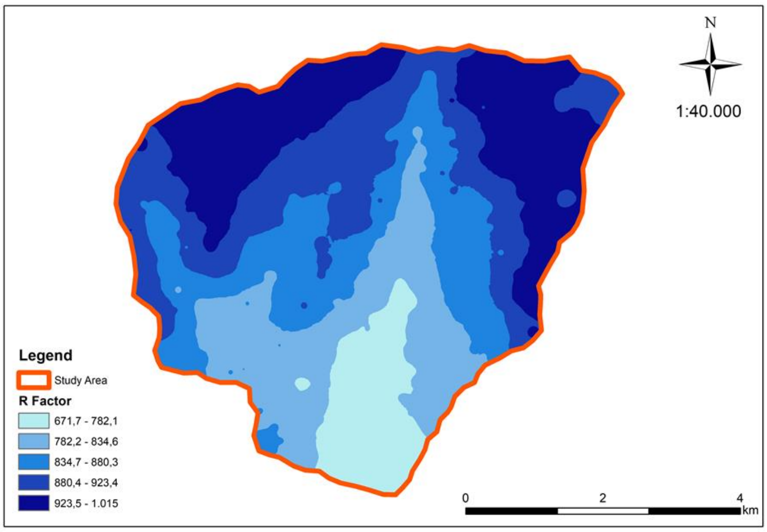


Figure 2. Narlıdere watershed R factor map

2.3.2. Soil erodibility factor (K)

Soil erodibility, or its resistance to erosion, depends on its structural and physical properties. Properties such as grain size (texture), structure, organic matter content, and water permeability determine soil erosion resistance. While some soils are resistant to erosive forces, others can be easily broken down and eroded (Balcı, 1996). One of the most important factors in calculating the K factor is the percentage of silt present in the upper soil layer (surface soil), as silt readily breaks down to form crusts, which lead to high runoff rates (Al Rammahi and Khassaf, 2018).

The K factor value was calculated using equations developed by Williams (1995) and Neitsch et al. (2000). The K factor value was determined by taking into account the amount of organic matter and soil texture and structure (Sönmez, 1994). The equations for the K factor are explained below (Equations 3, 4, 5, and 6).

$$f_{csand} = \left\{0.2 + 0.3 \times \exp\left[-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100}\right)\right]\right\}, \tag{3}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}, \tag{4}$$

$$f_{orgc} = \left\{1 - \frac{0.25 \times orgC}{orgC + \exp(3.75 - 2.95 \times orgC)}\right\}, \tag{5}$$

$$f_{hisand} = \left\{1 - \frac{0.7 \times \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right]}\right\}, \tag{6}$$

According to equations 3, 4, 5 and 6, ms: represents the percentage of sand content, msilt: represents the percentage of silt content, mc: represents the percentage of clay content and orgC: represents the amount of organic carbon. The K factor values vary between 0.022 and 0.014 (Figure 3).

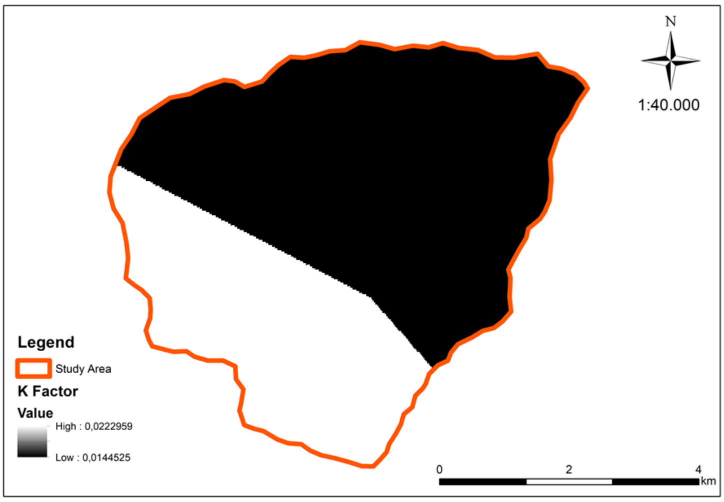


Figure 3. Narlıdere watershed K factor map

2.3.3. Topography factor (LS)

Topography is the most influential factor determining soil erosion risk. Equation (7) and ArcMap 10.8, along with the Digital Elevation Model (DEM) for the basin, were used to calculate the LS factor, which represents slope length and steepness. This method allows for detailed analysis of the topography by taking into account the area feeding the slope and its characteristics (Wilson and Gallant, 2000; Benavidez et al, 2018).

$$LS = \left(\frac{Xn}{22.13}\right)^{1.3} \quad \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \tag{7}$$

In Equation 7, X represents the concentration coefficient, which represents the area where the surface runoff is concentrated, n represents the cell size where the calculations are performed, and θ represents the slope angle (in degrees). The LS factor value varies between 0 and 726.75 (Figure 4).

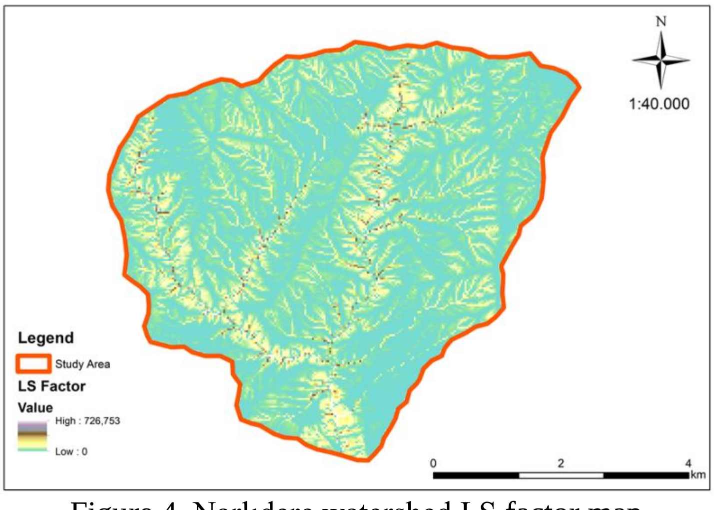


Figure 4. Narlıdere watershed LS factor map

2.3.4. Vegetation factor (C)

The C factor represents the cover management factor, which varies depending on the type and density of vegetation. Generally, vegetation has a significant impact on erosion by reducing the kinetic energy of raindrops before they reach the soil. Compared to other factors, the C factor plays a significant role in increasing or decreasing soil loss in a short period of time.

In this study, it was determined using forest management plan maps. Land use in the study area is categorized as forest, residential, agricultural, etc. C factor values were determined by scientists. A more common and easy method is to determine C factor values by referencing areas with similar vegetation or studies conducted in the same region (Benavidez et al., 2018). The C factor value ranges from 0 to 0.07 (Figure 5).

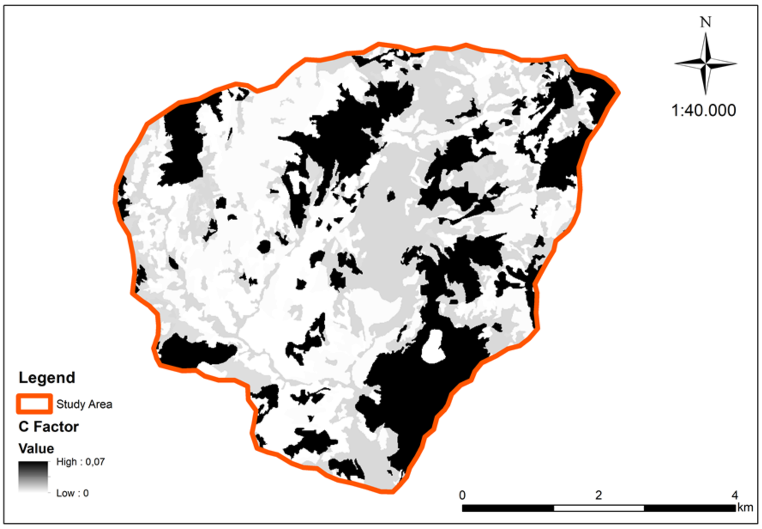


Figure 5. Narlıdere watershed C factor map

2.3.5. Support practice factor (P)

The P factor represents soil conservation measures. Soil tillage practices applied after erosion accelerates or slows down along the slope indirectly affect erosion processes. Research on spatially determining the P factor is quite limited in studies covering large areas. Since soil erosion prevention practices are used to a limited extent in our country, methods that directly affect the P factor are not widely applied. In this context, field observations in the Narlıdere Watershed revealed no soil conservation measures. Therefore, the standard P factor value of P=1.0 was used in this study (Wischmeier and Smith, 1978).

2.3.6. Estimated total erosion amount

Calculations were performed by combining all model factors within the map created using the RUSLE method to estimate erosion. Using existing thematic maps, these factors were combined using the Raster Calculator command in ArcMap software, and a map for factor A (annual average soil loss) was generated. In the Narlıdere Watershed, annual average soil loss was calculated using the RUSLE model. As a result of the analyses, the highest erosion value was determined to be 317.85 tons/ha/year (Figure 6).

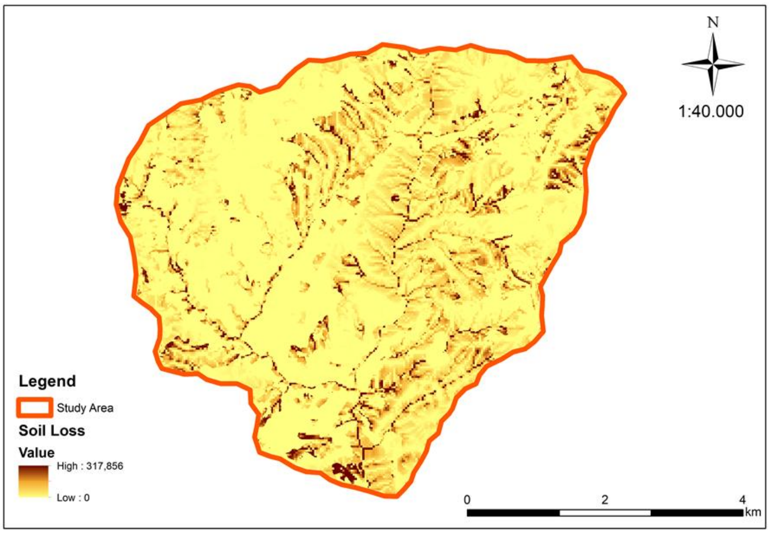


Figure 6. Narlıdere watershed RUSLE soil loss map

3. RESULTS AND DISCUSSION

RUSLE factors were determined in the Narlıdere Watershed and the amount of soil loss was revealed. As a result, the average annual soil loss was calculated as 2.10 tons/ha/year and 6697.36 tons/year. In the Sincanlı Basin, the average annual soil loss was calculated to vary between 0 and 14 tons/ha/year (Erkal and Yıldırım, 2012). In the study conducted in Ekinne Reservoir, the average annual soil loss was calculated as 15.6 tons/ha/year (Özcan, 2016). In another study conducted in the Veliköy Basin, the average soil loss was determined as 3.9 tons/ha/year, and it can be said that the results from the Sincanlı, İhsaniye, and Şuhut Basins are similar (Tüfekçioğlu et al, 2018). A study conducted in the Narlıdere Watershed examined the impact of different land uses on soil erosion. The K factor, which represents the susceptibility to soil erosion in the basin, ranged from 0.022 to 0.014. The total amount of erosion was calculated as 6697.36 tons throughout the basin. Because pastures have a low slope and are characterized by forest characteristics, losses were limited. Jiang et al. (2015) determined an average loss of 52.1 t/ha/year in the Jisnh River Basin, revealing that agricultural and pasture lands were the most affected land types.

4. CONCLUSION AND SUGGESTIONS

Soil erosion is a critical environmental problem for sustainable development and is effectively analyzed using RUSLE and GIS techniques. In the Emine Creek Basin, soil conservation measures have reduced potential soil loss by 38% over 50 years; if these measures were not implemented, this loss would have been negatively impacted by 353%. Improvements in the C and P factors have been found to reduce erosion risk approximately fourfold. This RUSLE study highlights the importance of conservation measures in semiarid and low-vegetation areas and highlights the need for further research on different climatic conditions and implementation strategies. In addition to focusing on the complex dynamics and interactions among the R, K, LS, C, and P factors, sustainable solutions can be developed through a thorough understanding of the interactions of the factors affecting soil erosion and cost-benefit analyses.

The findings from the Narlıdere Watershed highlight the significance of slope in accelerating soil erosion, as reflected in the LS factor, with the basin’s average slope being around 2%. Increased slope steepness substantially elevates erosion rates, with slope increases from 5%

to 10% and 15% leading to threefold and fivefold increases in erosion, respectively (Balcı and Ökten, 1987). Comparative studies confirm similar patterns elsewhere: in Pakistan's Swat region, annual potential soil loss reached 173,816 t/ha/year, exceeding 10,000 t/ha/year in some areas (Zhang et al., 2024); in Ethiopia, RUSLE-based estimates ranged from 12.94 to 576 t/ha/year (Terefe et al., 2025); and in Morocco's Loukkos Basin, projections for 1999–2040 indicated an annual soil loss of 111.51 t/ha/year due to climate change (Fatima et al., 2025). Within Narlıdere, the C-factor peaked in agricultural lands at 0.07, while forested areas exhibited minimal erosion thanks to vegetation cover and soil biota. Steep agricultural lands (>28% slope) are under unmanaged cultivation, whereas areas with 8–20% slopes require conservation practices such as improving humus content to enhance soil structure and infiltration. For rangelands, rotational resting is recommended to promote natural regeneration. Overall, the study emphasizes the necessity of sustainable land management and conservation planning, supporting the United Nations Sustainable Development Goal 2 (Zero Hunger) by addressing the threats of erosion to food security and long-term agricultural productivity.

REFERENCES

Aksoy, H., and Kavvas, M. L. (2005). A review of hillslope and watershed scale erosion and sediment transport models. *Catena, 64*(3), 247–271. https://doi.org/10.1016/j.catena.2005.08.008

Al Rammahi, A. H. J., and Khassaf, S. I. (2018). Estimation of soil erodibility factor in RUSLE equation for Euphrates River watershed using GIS. *GEOMATE Journal, 14*(46), 164–169.

Ardel, A., Kurter, A., and Dönmez, Y. (1969). *Applied climatology*. Istanbul University, Institute of Geography Publications, Tas Printing House.

Arnoldus, H. M. J. (1977). Methodology used to determine the maximum potential average soil loss due to sheet and rill erosion in Morocco. In *Assessing soil degradation* (FAO Soils Bulletin No. 34s, pp. 8–9). Food and Agriculture Organization.

Avcı, B. C., Kesgin, E., Atam, M., and Tan, R. I. (2023). Spatial-temporal response of sediment loads to climate change and soil conservation practices in the Northern Aegean Watershed, Türkiye. *Water, 15*(15), 2461. https://doi.org/10.3390/w15152461

Bai, L., Shi, P., Li, Z., Li, P., Zhao, Z., Dong, J., Cui, L., Niu, H., Zu, P., and Cao, M. (2023). Synergistic effects of vegetation restoration and check dams on water erosion in a slope-gully system. *Land Degradation and Development, 34*(17), 3581–3592. https://doi.org/10.1002/ldr.4892

Balcı, N. (1996). *Soil conservation*. University Publication No. 3947, Faculty of Forestry Publication No. 439, Istanbul.

Balcı, N., and Ökten, Y. (1987). *Flood control*. Karadeniz Technical University Press.

Benavidez, R., Jackson, B., Maxwell, D., and Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): With a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences, 22*(11), 6059–6086. https://doi.org/10.5194/hess-22-6059-2018

Beskow, S., Mello, C. R., Norton, L. D., Curi, N., Viola, M. R., and Avanzi, J. C. (2009). Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. *Catena, 79*(1), 49–59. https://doi.org/10.1016/j.catena.2009.05.010

Biggelaar, C. D., Lal, R., Eswaran, H., Breneman, V. E., and Reich, P. F. (2003). Land quality, agricultural productivity, and food security: Biophysical processes and economic choices at local, regional, and global levels. In K. Wiebe (Ed.), *Crop yield losses to soil* *erosion at regional and global scales: Evidence from plot-level and GIS data* (pp. 262–279).

Chen, T., Niu, R.-Q., Li, P.-X., Zhang, L.-P., and Du, B. (2010). Regional soil erosion risk mapping using RUSLE, GIS, and remote sensing: A case study in Miyun Watershed, North China. *Environmental Earth Sciences, 60*(5), 1017–1026. https://doi.org/10.1007/s12665-009-0255-4

Chiang, Y., Li, J., and Chen, S. (2023, April 23–28). Effects of vegetation root on erosion degree under different arrangements of river banks. In *Proceedings of the EGU General Assembly 2023*. Vienna, Austria.

Curebal, İ., and Ekinci, D. (2006). Erosion analysis in the Kızılkeçili Stream watershed using GIS-based RUSLE method. *Turkish Geographical Review, 46*, 115–129.

Delgado, D., Sadaoui, M., Ludwig, W., and Méndez, W. (2022). Spatio-temporal assessment of rainfall erosivity in Ecuador based on RUSLE using satellite-based high frequency GPM-IMERG precipitation data. *Catena, 219,* 106597. https://doi.org/10.1016/j.catena.2022.106597

Dönmez, Y. (1979). *General climatology and climate studies*. Istanbul University Faculty of Letters Publications, No. 2506.

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Adgo, E., Fenta, A. A., Meshesha, D. T., Berihun, M. L., Sultan, D., and Vanmaercke, M. (2022). Global analysis of cover management and support practice factors that control soil erosion and conservation. *International Soil and Water Conservation Research, 10*(2), 161–176. https://doi.org/10.1016/j.iswcr.2021.07.006

Erkal, T., and Yıldırım, U. (2012). Soil erosion risk assessment in the Sincanlı sub-watershed of the Akarçay Basin (Afyonkarahisar, Turkey) using the Universal Soil Loss Equation (USLE). *Ekoloji, 21*(84), 18–29. https://doi.org/10.5053/ekoloji.2012.841

Erpul, G., İnce, K., Demirhan, A., Küçümen, A., Akdağ, M. A., Demirtaş, I., Sarıhan, B., Çetin, E., and Şahin, S. (2020). *Water erosion provincial statistics—Soil erosion control strategies (sustainable land/soil management practices and approaches)* (1st ed.). General Directorate of Combating with Desertification and Erosion.

Fatima, B., Rachid, H., Abdeldjalil, B., Abdessalam, O., Mohamed, B., Alfagham, A. T., and Tariq, A. (2025). Monitoring and forecasting water erosion in response to climate change effects using the integration of the global RUSLE/SDR model and predictive models. *Applied Soil Ecology, 206*, 105910. https://doi.org/10.1016/j.apsoil.2023.105910

Ganasri, B. P., and Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS: A case study of Nethravathi Basin. *Geoscience Frontiers, 7*(6), 953–961. https://doi.org/10.1016/j.gsf.2015.11.007

Ghosal, K., and Bhattacharya, S. D. (2020). A review of RUSLE model. *Journal of the Indian Society of Remote Sensing, 48*(4), 689–707. https://doi.org/10.1007/s12524-020-01119-8

Huang, B., and Liu, Z. (2023). Soil and water conservation effects of contour reverse slope terraces on red clay sloping farmland against short and heavy rainfall. *Geofluids, 2023,* Article 9479632. https://doi.org/10.1155/2023/9479632

Issaka, S., and Ashraf, M. A. (2017). Impact of soil erosion and degradation on water quality: A review. *Geology, Ecology, and Landscapes, 1,* 1301053. https://doi.org/10.1080/24749508.2017.1301053

Jiang, L., Yao, Z., Liu, Z., Wu, S., Wang, R., and Wang, L. (2015). Estimation of soil erosion in some sections of Lower Jinsha River based on RUSLE. *Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, China*.

Mukharamova, S., Saveliev, A., Ivanov, M., Gafurov, A., and Yermolaev, O. (2021). Estimating the soil erosion cover-management factor at the European part of Russia. *ISPRS International Journal of Geo-Information, 10*(12), 645. https://doi.org/10.3390/ijgi10120645

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., and Williams, J. R. (2000). *Erosion Soil and Water Assessment Tool: Theoretical documentation*. Texas Agricultural Experiment Station.

Olivier, G., Van DeWiel, M. J., and De Clercq, W. P. (2023). Intersecting views of gully erosion in South Africa. *Earth Surface Processes and Landforms, 48*(1), 119–142. https://doi.org/10.1002/esp.5506

Ozcan, A. U., Erpul, G., Basaran, M., and Erdogan, H. E. (2008). Use of USLE/GIS technology integrated with geostatistics to assess soil erosion risk in different land uses of Indagi Mountain Pass—Çankiri, Turkey. *Environmental Geology, 53*(8), 1731–1741. https://doi.org/10.1007/s00254-007-0863-5

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., and Montanarella, L. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy, 48*, 38–50. https://doi.org/10.1016/j.landusepol.2015.05.021

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E. H., Poesen, J., and Alewell, C. (2015). Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. *Environmental Science and Policy, 51*, 23–34. https://doi.org/10.1016/j.envsci.2015.03.012

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., and Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. *Environmental Science and Policy, 54*, 438–447. https://doi.org/10.1016/j.envsci.2015.08.012

Ranzi, R., Le, T. H., and Rulli, M. C. (2012). A RUSLE approach to model suspended sediment load in the Lo River (Vietnam): Effects of reservoirs and land use changes. *Journal of Hydrology, 422–423*, 17–29. https://doi.org/10.1016/j.jhydrol.2011.12.034

Renard, K. G., Foster, G. R., Weesies, D. K. M., and Yoder, D. C. (1997). *Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE).* USDA.

Renard, K. G., Foster, G. R., Weesies, G. A., and Porter, J. P. (1991). Revised universal soil loss equation (RUSLE). *Journal of Soil and Water Conservation, 46*(1), 30–33.

Renard, K. G., and Freimund, J. R. (1994). Using monthly precipitation data to estimate the R-factor in the revised USLE. *Journal of Hydrology, 157*, 287–306. https://doi.org/10.1016/0022-1694(94)90010-4

Robinson, D. A., Panagos, P., Borrelli, P., Jones, A., Montanarella, L., Tye, A., and Obst, C. G. (2017). Soil natural capital in Europe: A framework for state and change assessment. *Scientific Reports, 7*, 6706. https://doi.org/10.1038/s41598-017-06315-8

Schmidt, S., Alewell, C., and Meusburger, K. (2018). Mapping spatio-temporal dynamics of the cover and management factor (C-factor) for grasslands in Switzerland. *Remote Sensing of Environment, 211*, 89–104. https://doi.org/10.1016/j.rse.2018.04.012

Shah, P., and Dahal, K. (2023). Problems associated with implementation of bioengineering in hill road construction in Nepal. *Journal of Engineering and Applied Sciences, 70*, 30.

Shaikh, S., Palanisamy, M., and Mohideen, A. R. S. (2020). Estimate the annual soil loss in Kummattipatti Nadi watershed using RUSLE model through geospatial technology. *Geodesy and Cartography, 46*(2), 75–82. https://doi.org/10.3846/gac.2020.9761

Shan, Y., Zhong, Q., Chen, S., Wang, L., Chen, X., Mei, S., and Yang, M. (2023). Experimental study on predicting head-cut migration rate of check dams. *Journal of Hydrology, 624*, 129882. https://doi.org/10.1016/j.jhydrol.2023.129882

Sönmez, K. (1994). *Soil conservation textbook* [Toprak Koruma Ders Kitabı]. Atatürk University, Faculty of Agriculture Publications No. 169.

Teng, H., Viscarra Rossel, R. A., Shi, Z., Behrens, T., Chappell, A., and Bui, E. (2016). Assimilating satellite imagery and visible–near infrared spectroscopy to model and map soil loss by water erosion in Australia. *Environmental Modelling and Software, 77*, 156–167. https://doi.org/10.1016/j.envsoft.2015.12.006

Terefe, B., Melese, T., Tsegaye, A., Yibeltal, T., Anagaw, A., Temesgen, F., and Mencho, B. B. (2025). Soil loss estimation in Ethiopia: A comprehensive review of the RUSLE model integrated with geospatial technologies. *Discover Sustainability, 6*, Article 334. https://doi.org/10.1007/s43621-025-00034-9

Tüfekçioğlu, M., Yavuz, M., Vatandaşlar, C., Dinç, M., Duman, A., and Tüfekçioğlu, A. (2018). Assessing and mapping erosion risk for Velikoy Sub-watershed within Coruh River Basin in Turkey. *Journal of Natural Disasters and Environment, 4*(2), 210–220.

Williams, J. R. (1995). Chapter 25: The EPIC model (pp. 909–1000). In *Computer models of watershed hydrology*. Water Resources Publications.

Wilson, J. P., and Gallant, J. C. (2000). Digital terrain analysis. In J. P. Wilson and J. C. Gallant (Eds.), *Terrain analysis: Principles and applications* (pp. 1–28). John Wiley and Sons.

Wischmeier, W. H., and Smith, D. D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning* (No. 537, 1st ed.). U.S. Department of Agriculture.

Wischmeier, W. H., and Smith, D. D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. *Agricultural Handbook* (No. 537). U.S. Department of Agriculture, Washington, DC, USA.

Yu, B., and Rosewell, C. J. (1996). A robust estimator of the R-factor for the Universal Soil Loss Equation. *Transactions of the ASAE, 39*, 559–561. https://doi.org/10.13031/2013.27609

Yüksel, E. E., and Karan, Ö. F. (2024). Determining climate types according to Thornthwaite method: The case of Bursa province. *Artvin Çoruh University Journal of Forestry Faculty, 25*(1), 151–168. https://doi.org/10.17474/artvinofd.123456

Zerihun, M., Mohammedyasin, M. S., Sewnet, D., Adem, A. A., and Lakew, M. (2018). Assessment of soil erosion using RUSLE, GIS and remote sensing in NW Ethiopia. *Geoderma Regional, 12*, 83–90. https://doi.org/10.1016/j.geodrs.2017.12.002

Zhang, L., Haseeb, M., Tahir, Z., Tariq, A., Almutairi, K. F., and Soufan, W. (2024). Assessment of soil erosion dynamics and implications for sustainable land management: A case study using the RUSLE model. *International Journal of Sediment Research*. https://doi.org/10.1016/j.ijsrc.2024.03.007

Forest Road Engineering in Mountainously Forests of Türkiye

Mehmet Eker[1*], Abdullah Emin Akay[2]

[1]Forest Engineering Department, Faculty of Forestry, Isparta University of Applied Sciences, Isparta, Türkiye
[2]Forest Engineering Department, Faculty of Forestry, Bursa Technical University, Bursa, Türkiye
*mehmeteker@isparta.edu.tr

Abstract

In many parts of the world, forest roads, which are the main element of lateral infrastructure, are used for all kinds of forestry activities. In Türkiye, the road length required for the optimal opening-up of approximately 24 million hectares of forest land is about 360,000 km. Currently, there are over 300,000 km of roads in which nearly 230,000 km are forest roads. Since this situation has many advantages and disadvantages in terms of technical, economic and ecological aspects, it also constitutes one of the important forestry issues. The objectives of this study were to provide descriptive information about forest roads in Türkiye, to describe how forest road engineering works, to present information on road construction mechanization/technologies and to make evaluations that could help to analysis the forest road network in technical and environmental terms so that it can be compared to regions with similar mountainous areas. In this context, the types and geometric standards of forest roads were introduced, the forest road construction hierarchy was listed, and processes performed in the planning, project and application stages up to the road construction were described. Road construction techniques and mechanization were also described and the findings on the technical efficiency and environmental impacts of forest roads were analysed through the road network parameters (i.e road density, road intervals, opening-up ratio, occupation area, etc.) for the assessment of the existing road network.

Keywords: *Forest roads, road networks, road analysis, Türkish forestry, road metrics.*

1. INTRODUCTION

The forest roads are built up for afforestation and reforestation, forest protection, utilization and operationalization. The functions of forest roads (Gümüş et al., 2008) are generally similar all over the world and can be summarized as follows:

- Terrain accessibility (*Opening-up of forests*)
- Infrastructure and spatial arrangement (*internal division network, border, storage, etc*.)
- Transportation and handling (*for people-personnel, products, goods, etc.*)
- Conservation (*fire management, combat to insects, etc*.)
- Sustainable utilization (*supply chain of whole forest products and reverse logistics*)
- Strategic facility function (*defense logistics*)

Road engineering is an engineering discipline that encompasses the geometric design, structural dimensioning, material selection, drainage systems, and maintenance and repair processes of highways, and focuses on the planning and construction of transportation infrastructure (Papagiannakis and Masad, 2024). Road engineering is based on the design of roads in accordance with standards to increase transportation efficiency, support economic development, and safely direct vehicle traffic. Forest road engineering, on the other hand, differs from general road engineering in that it encompasses designs with lower standards but high environmental sensitivity, responding to the specific needs of forestry activities in natural terrain conditions (Figure 1).


Figure 1. The forest road laying out through unharvested and harvested stands

Because forest roads are often constructed on steeply sloped, rugged, loosely structured, and erosion-prone sites, the engineering of such roads requires more complex decision-making processes regarding road route selection, soil stability, drainage planning, and the selection of construction machinery (Acar and Eker, 2001a; Akay et al., 2021).

While the purposes and functions of forest roads are generally similar, many characteristics, such as regional and local conditions for forest road engineering, road functions, technical specifications, and road quality can vary from country by country. For example, forest roads, unique to Türkiye, are not solely focused on transporting forest products; they have multiple benefits and rationales (Demir and Hasdemir, 2005).

The quantity and quality of forest roads vary depending on a country's understanding of forestry, forest availability, forestry conditions, topographical conditions, economic status, and technological potential. In addressing forest road problems, practices from countries with similar conditions, or solutions from developed countries for similar problems, are utilized based on the needs (Dykstra and Heinrich, 1996).

The purpose of this study was to desribe forest road characteristics in Türkiye and how forest road engineering works in state-owned forestry system. Besides, information on technical and environmental aspects of road construction were provided to make a comparision with similar mountainous areas. To carry out this study, various source materials such as official statistics on state forests and forestry, activity reports, budget reports, legal legislation (laws, regulations, communiques, etc.), road construction machinery catalogues, literature, field observations, personal experiences from previous studies, and personal communications with forest manager and engineeer were evaluated. To explain forest road engineering and management, information was provided on the unique conditions of forests and forestry in Türkiye. After discussing the existence of forest roads in Türkiye, detailed information about forest roads was provided.

2. FOREST RESOURCES AND FORESTRY IN TÜRKİYE

In order to understand the necessity of forest roads in a country like Türkiye, which has a mountainous and intersecting terrain, it is necessary to briefly describe the forest areas and forestry where the function of the roads is needed. Türkiye connects Asia and Europe and is located at the intersection of three continents, as well. According to the 2024 census, its population is approximately 86 million and 111 people live per square kilometer. It consisting of mountainous plateaus, is surrounded by sea on three sides. The average elevation above sea level is 1,141 m. Türkiye's total area is approximately 78.5 million hectares, and its land use includes 23.4 million hectares (M ha) of forestland, 24.4 M ha of farmland, 14.6 M ha of grassland, 1 M ha of lakes and streamlands, and 16.7 M ha of other lands. Approximately 30% of Türkiye's surface area is forest land and 59% of this forest area is productive high forests according to data of 2024 (Table 1) (GDF, 2025).

Table 1. Distribution of forest land (ha)

	Total	Productive	Degraded
Total	**23 363 084**	13 813 598	9 549486
High forest	22 290 533	13 391 678	8 897 855
Coppice	1 072 551	420 920	651 631

The total growing stock of forest areas is over 1 billion 79 million cubic meters (Table 2). The annual current increment in forests in this situation is approximately 50,9 million cubic meters (Table 3). On the other hand, approximately 50% of forest areas are reserved for ecological functions and slightly more than 40% are managed for economic functions (Table 4) (GDF, 2025).

Table 2. Distribution of growing stock (m^3)

	Total	Productive	Degraded
Total	**1 798 061 769**	**1 735 086 167**	**62 975 602**
High forest	1 782 405 848	1 722 728 230	59 677 618
Coppice	15 655 921	12 357 937	3 297 984

Table 3. Annual increment (m^3)

	Total	Productive	Degraded
Total	**50 955 500**	**49 004 363**	**1 951 137**
High forest	50 050 271	48 310 269	1 740 002
Coppice	905 229	694 094	211 135

Table 4. Forests by general functions (ha)

Functions	Sub-Functions	Total
Economic	Production of Forest Products	**9 346 665**
Ecological	Nature Protection, Preventing Erosion, Climate Protection	**11 935 673**
Socio-cultural	Hydrologic, Public Health, Aesthetic, Recreation, Scientific, etc.	**2 080 733**
	Grand total	**23 363 071**

Forest lands are generally located in sloping, mountainous, and hillside terrain, with an average slope exceeding 40%. Türkiye is divided into seven distinct geographical regions, and temperature and precipitation patterns vary significantly across these regions. However, forests in the northern and eastern regions are more mountainous and composed of shade trees, while the western and southern regions contain light trees. Karst terrains also dominate the southern and western regions in terms of soil structure. Mountainous forests have hard, rocky ground. Soil engineering in such terrain is quite challenging for forest road operations.

Almost all forests are state-owned. State forests are divided into regions and enterprises and managed by state-owned forest enterprises/administrations. The most distinctive feature of state forest management is its prioritization of protecting forest villagers and developing forest villages with variable subsidies. The state established the General Directorate of Forestry as a central administrative unit for forest management, and regional directorates, districts, and enterprises were established under this general directorate (Figure 2). The smallest unit of implementation for forestry activities is the compartment or stand-based.

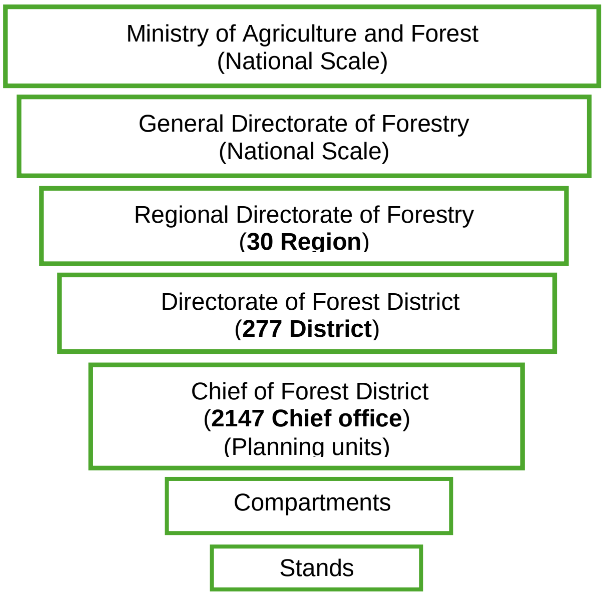


Figure 2. The scheme of forest administration to spatial arrangement

Within this forest resources and forestry structure, more than 20 million m^3 of wood raw material is harvested and transported via forest roads in Türkiye every year (Figure 3) (GDF, 2025).

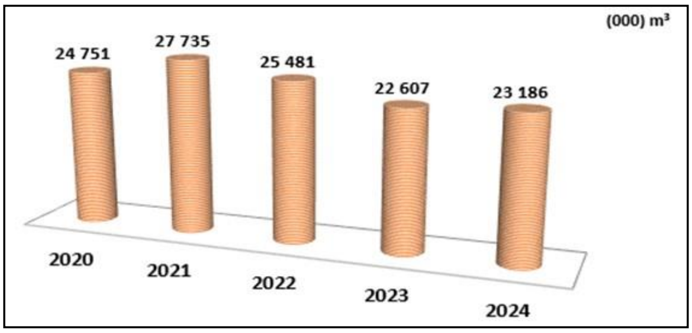


Figure 3. Roundwood production between 2020-2024 years

3. FOREST ROADS IN TÜRKİYE

3.1. Forest Road Inventory

It is planned that the forest roads, which constitute the most important transportation infrastructure and are necessary for harvest operations, will be more than 366,000 km. Currently, the total length of the roads passing through the forest is close to 300,000 km. The number of forest roads exceeds 237,000 km. With this amount of roads, 90% of the forests can be accessible. Road density is between 12 and 25 meters per ha. Opening-up ratio is approximately over the 70 % for the forest roads within 500 m distance to road. Most of the road segments in forest road network pass through highly sloped areas (Figure 4) (GDF, 2025).

Figure 4. Forest road in mountainous and sloping terrain

4.2. Legislations for Forest Roads

Forest roads must be constructed within the framework of rules specific to Türkiye and adhere to specific principles. The constitution, forest law, environmental protection laws, and forestry legislation dictate that forest roads be planned, constructed, and operated according to specific principles to protect forest ecosystems, ensure the well-being of villagers within forests (support rural development), and facilitate forest management. Forestry operations is planned and managed according to this legislation, which is organized according to a hierarchy of norms. Within the framework of this legislation, there is both a regulation (Regulation on the Forest Road Network Plans) and a communiqué (Communiqué No. 292: Guide for Planning, Construction, and Maintenance of Forest Roads) for forest roads (GDF, 2008). This communiqué clearly outlines the rules/principles for planning, construction, and maintenance of forest roads.The basic rules for forest roads are listed as follows;

- Economy
- Functionality
- Safety
- Aesthetics
- Sustainable use (Technical, Economic, Ecological, and Social sustainability)

As is the case throughout the world, some basic principles must be followed in the building of forest roads in Türkiye. The main principles for forest roads are based on i) Road Network Planning Principles, ii) Road Design (Project) Principles, and iii) Road Construction Principles. Some principles to be followed in a forest road building as mentioned below**;**

- Opening up the planning units in an integrated manner
- Maximizing their functional benefits
- Contributing to the development of forest communities
- Minimizing forest area loss and area of disturbance
- Ensuring continuous and safe transportation
- Minimizing total building costs
- Avoiding building roads in rocky, swampy, landslide areas

- Avoiding damaging forests, residential and agricultural areas
- Avoiding alteration of natural drainage patterns
- Avoiding problematic areas (cultural assets, endemic species, etc.)
- Not exceeding 1% of the total area allocated to forest roads
- Not planning parallel and very close roads (road spacing)
- Arranging environmentally friendly roadlayout
- Having a short route between the cardinal points
- Providing suitable for traffic all year round
- Having sufficient carrying capacity
- Minimizing roads in national parks and protected forests
- Avoiding steep ground with slopes over 75 percent
- Using stable cut and fill slope angles
- Having a stable, structurally sound road surface
- Using slope stabilization, structures, and drainage

4.3. Characteristics of Forest Roads

Some of the structural specifications that make up the general characteristics of forest roads and distinguish them from other highways are briefly summarized in the following items. Forest roads are;

- Dirt roads
- Low volume roads
- Mostly secondary roads
- Mostly unpaved roads
- Located on slopes
- Distributing in the form of a network in the forest
- Planning basin-based
- Connecting mandatory nodes (cardinal points)
- Trying to fully open the planning unit to operation
- Containing opposite slopes through road layout
- Containing intense and narrow curves
- Sloping, which cannot be above 12% and below 2%
- Quite low cost
- Technically and economically different from other highways

Legal regulations on forest roads, Communique No: 292, technically define the types and geometrical characteristics of forest roads (Table 5) (GDF, 2008). Forest roads can be subjected to a taxonomic classification in terms of various aspects such as construction site, superstructure status, and intended use, as well as their technical characteristics (Table 6) (Erdaş, 1997; Bayoğu, 1997; GDF, 2008).

When deciding on the nature of a new road segment to be constructed in a forest planning unit, some general factors that influence the selection of the road type are listed below. These are;

- The topography of the land (*Land slope, bearing capacity, ground structure, etc.*)
- The purpose and importance of the road
- The location of the road (*Whether the roads will be built in a valley, slope or on ridge*)
- The amount of harvesting yield (Erdaş et al, 2014)
  - Annual wod production > 50000 m^3; main forest road
  - Annual wood production 25000-50000 m^3; A-Type Secondary forest road
  - Annual wood production < 25000 m^3 and less; B- Type Secondary forest road

Table 5. Geometrical Standards of Forest Roads in Türkiye

Road Features	Unit	Main forest road	Secondary Forest Roads				Tractor roads
			A-Type	B-Type			
				HBT	NBT	EBT	
Platform width	m	7	6	5	4	3	3,5
Number of lanes	-	2	1	1	1	1	1
Maximum slope	%	8	10	9	12	12	20
Minimum radius	m	50	35	20	12	8	8
Lane width	m	3	3	3	3	3	3
Shoulder width	m	0.50	0,50	0,50	0,50	0,50	
Ditch width	m	1	1	1	1	0,50	
Pavement width	m	6	5	4	3	3	
Bridge width	m	7+(2x0.6)	6+(2x0.6)	5+(2x0.6)		4+(2x0.6)	

Note: HBT: High standard B type forest road, NBT: Normal B type forest road, EBT: Extreme B type forest road.

Table 6. Types of forest roads

Technical Specifications	Road Superstructure	Utilization	Location
Main Access Roads (permanent) Secondary Roads (seasonal) "A-Type" secondary roads "B-Type" secondary roads - High standardized B-Type - Normal sized B-Type - Extreme sized B-Type	▪ Dirt Road ▪ Gravel Road ▪ Stabilized ▪ Concrete Road ▪ Paved Road	• Truck Road • Tractor Road • Skidding Road • Contact Road • Collective Road	• Valley roads • Stream roads • Ridge roads • Slope roads

4.4. Forest Road Engineering and Management

Road engineering and management including the design, construction, and use of forest roads (Akay and Sessions, 2004; IUFRO, 2025). Hierarchy on forest road building stages in Turkish forestry:

1) Planning (Road network-layout plans)
2) Projecting (Route design for road location)
3) Application (Survey and flagging road location on the ground)
4) Construction
5) Maintenance

4.4.1. Planning practices

Planning process and method are based on the mentioned below;

- Determining specific conditions of the planning unit
- Detecting purposes, functions and tasks of the road
- Decision making for main transport direction
- Assessment on topography and geology
- Determining cardinal nodes (positive and negative points)
- Decison making on road length for optimal opening-up
- Evalauting the possibility of using existing roads
- Drawing the road route (on contour lines of manual or digital maps)
- Drawing alternative road routes for road layout
- Decision making on the appropriate routes to multiple criteria

There are certain criteria that must be followed when planning and through other building process for forest roads. These are (Eker and Ada, 2011);

- Technical criteria (*geometrical standards, topographical conditions, planning principles, management objectives, user demands and needs, etc.*)
- Economic criteria (*least building costs, minimizing transport costs, shortest paths, minimum loss of productive area, etc.*)
- Social criteria (*access into forest and rural areas, connection forest villages, etc*.)
- Ecological criteria (*soil/surface erosion, drainage patterns, water courses, habitat fragmentation, forest fire management, etc*.)

The planning tools and materials used in the implementation of this planning method can be listed as follows; remote sensing softwares (GIS (ArcGIS), CAD (NetCAD, Autocad), etc.), satellite imagery, aerial photography, UAV (and LIDAR) imagery, and maps (topographic, geology-geomorphology, stand/compartment, cadastre maps, etc.). As a result of the planning method followed by taking into account forest road planning principles and criteria, a unique forest road network plan is obtained as an output for each forest planning unit (Figure 5 and 6). Features of a road network plan as is;

- Specific for each planning unit
- Management is beloging to State Foretsry
- Tactical level
- Using as macro transportation plan
- Renewed with forest management plans
- Revised on average every 10 years after constructed roads
- Forest engineers make the plans

4.4.2. Field Survey, Application and Project Practices

The task to be done in the second stage after the planning of forest road network may differ depending on the method to be followed. Road (location) route reconnaissance is based on two method, as classic and theoretical method. While the classical method involves first making the application to field and then doing the project design, the theoretical method also involves first making the project design and then making the application for road route (Erdaş, 1997). In the classical method, the road's route is first determined by field survey and marked on the ground. Then, a road project for each segment is prepared on the map and in the office. In the theoretical method, called as photogrammetric method or modern method, the road route is determined on the map (using aerial photographs, satellite imagery, or precise data), a project is prepared as well in the office, and then the road route is marked on the field during the application process.

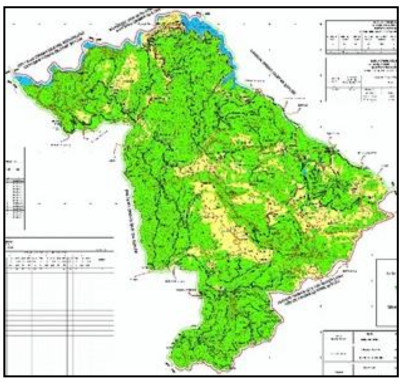


Figure 5. Forest road network plan

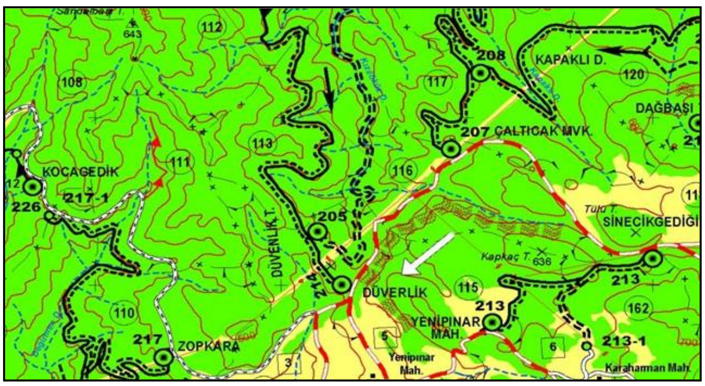


Figure 6. A section from the forest road network plan

In Türkiye, the state forest administrations currently follow the so-called classical method in the process for determining road routes. In the implementation of the classical method;

1) the field where the road route will be passed is examined in istu conditions and the road route (zero poligon) is determined on the field and marked to the land (Application and I. Reconnaissance),
2) the road project is prepared in the office using the field information and application data, and the approximate cost is calculated as well,
3) then the road is constructed and (as soon as the road construction is completed) the field survey is carried out again, the types and quantity of ground through which the road passes are determined by using the excavation slopes and the technical specifications of the road are measured and inspected (II. Reconnaissance), and
4) the final calculation is made, which will form the basis for payment for the road cost, using the completed excavation and filling works (the entitlement amount is calculated).

Field Survey:

Geological situation is surveyed, ground type of road segment is estimated via surface observation based on knowledge and experience for a feasible road route reconnaissance during the field survey. The (new) forest route should;

- connect positive cardinal points
- be segment basis
- meet the project standards
- consider the slope limits and opposite slopes during the passage
- be suitable for the main purpose of the road
- pass through stable geology, high bearing capacity and solid ground
- be the lowest costs in terms of construction and maintenance
- be as little as possible the earthworks and soil transportation
- pass through places balancing excavation and filling mass
- pass through places with the best drainage possibilities
- be made at right angles as much as possible
- be on state land without requiring expropriation
- be in good harmony with the existing road networks
- be shortest and tight (less curve and more alignment)
- be named with a code number per each segment (Figure 7).

Figure 7. Promotion sign of a forest road segment

***Application (Marking road location on the ground and route reconnaissance)*:**

The process of setting out the road route on the field is carried out after the project is drawn according to the theoretical method; while the classical method is carried out before the project is drawn. The road, outlined on the road network map and topographic map (after the forest road network plan is prepared), is mapped on its route in the field using a compass, inclinometer, total station, or GPS (Figure 8). If the classical method is used, the forest road route is measured and marked in a controlled manner (using an inclinometer) based on the road slope, using findings obtained through direct observation of the terrain through field survey. During the marking, level stakes and slope stakes of the road route (road axis) are marked in the field, visible to the machine operator (Figure 9).

Figure 8. Tools used in field resonnasiance for road route

Figure 9. Road route application studies

Project (Route) Design Practices (for a road segment):
Theoretical project design process and (modern) method for a road segment follow the mentioned steps, as is (Erdaş, 1997);

- Large scale map is produced (1/2000 or larger)
- Start and end points are marked on the map
- UAV or high resolution images are examined
- If possible, field reconnisance are completed
- Road type (geometric standards) are decided
- The land slope between the start and end points is calculated
- The road route in the forest road network plan is taken as basis
- Possible routes are considered
- The suitable road slope is calculated and the compass clearance is decided
- The zero line is marked and drawn on the contour line manual or digital map
- Straightening process is performed in zero polygons
- Curves (to radius limits) are placed
- Longitudinal profile is charted
- Cross section (profiles) are drawn
- Excavation and filling areas and volumes are calculated
- Cubage (volumetric) table is designed
- Material (distribution) profile is drawn
- Material distribution table is created

- Cost calculations are made and
- Technical report is prepared at last.

During the implementation of this method, a forest road project is (manually or digitally) created for each road segment (Figure 10) (Akay and Sessions, 2005; Akay, 2006), using precise data and maps obtained through various methods, with geographic information systems, and/or computer-aided drawing tools (eg.; netCAD, Civil 3D, etc.).

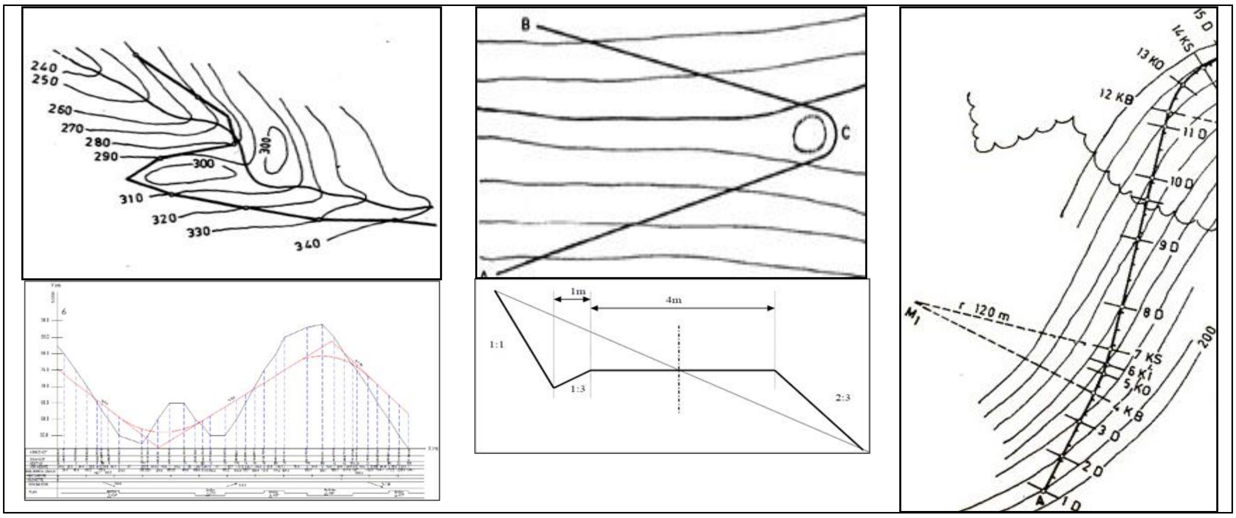


Figure 10. Examples of some steps of a forest road project

4.4.3. Forest Road Construction

In Turkish forestry, forest roads can be constructed either by the state forestry administration's own vehicles and personnel or by private forestry firms through various contracting systems via various tendering methods. However, the construction techniques are the same in both construction methods. Accordingly, construction process for a road segment follows the steps (Erdaş, 1997)**;**

- Site establishment and work organization
- Clearing of the construction area (log removal)
- Selecting the appropriate machine
- Breaking of rocks (blasting works)
- Soil leveling (excavation and filling works)
- Creating excavation and filling slopes
- Mass transport
- Subgrading
- Surfacing and shaping
- Road drainage

***Road Construction Machines*:**

Before starting construction, it is decided which construction machines should be used for the road, depending on the slope gradient of the land, the ground structure and the characteristics of the road will be built. Accordingly;

- if the terrain slope gradient is below 30-35 %, then dozers (bulldozer, tiltdozer or angledozer) can be used.
- If the terrain slope is above 35%, hydraulic excavators are used. In Turkish forestry, excavators have begun to be used in recent years for environmentally friendly forest

road construction (Winkler, 1999), and excavators are used in road construction in mountainous terrain (Acar ve Eker, 2001 and 2003).

- In terrain with mixed slope groups, both vehicles (dozer and excavator) are used together.
- If terrain with a slope between 20% and 40%, traxcavator can also be used.
- If the terrain is nearly flat and gentle slopes and the road route is short distanced, then backhoes are used in road construction (Figure 11).

Figure 11. Forest road machines (a:Bulldozer, b:Excavator, c: Traxcavator, d:Backhoe)

***Excavation and Filling*:**

Construction technique– *with hydraulic excavators*;

- Topsoil removal with bucket
- Excavating base
- Fill slope building
- Subgrade and cut shaping

Excavators ensure that excavation material flowing to the filling side is controlled and stored safely on the filling side for environmentally friendly road construction (Figure 12 and 13).

Construction technique– *with dozers;*

- Topsoil removal with bucket
- Shovelling with blade
- Scraping layer for road bed
- Subgrade and cut shaping (Figure 14).

In bulldozing road construction, the following methods can be applied depending on the ground characteristics, i)head digging, ii) side digging, iii) layer method, or iv) mixed excavation. The layer method is generally preferred (Figure 15).

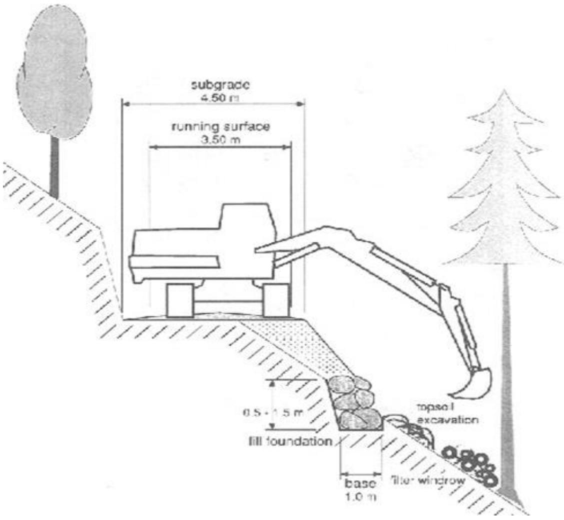


Figure 12. Construction technique

Figure 13. Excavation with excavators

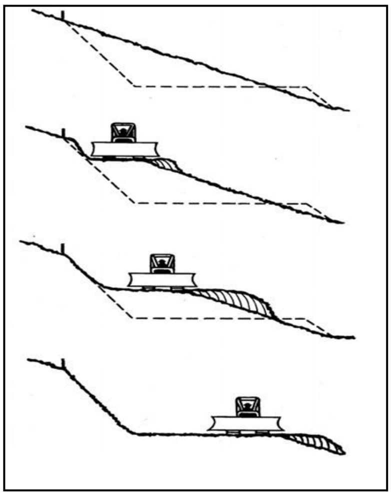


Figure 14. Construction technique

Figure 15. Shovelling with dozer

***Smoothing of subgrade*:**
After road excavation and backfilling, the subgrade is leveled to create the road platform. While in this state, the road platform is not suitable for wheeled vehicles, yet (Figure 16).

Figure 16. Smoothing with excavator for subgrade design

Subgrading (Base Level):

After the ground is excavated using various excavation techniques for forest road construction and the road axis is established at the desired elevations (Figure 17), the road surface is then leveled using construction machinery or, if possible, suitable vehicles. The road surface is then created using the same construction machinery. After this stage, it is possible for rubber-tired off-road vehicles to navigate this road, albeit with difficulty (Figure 18).


Figure 17. Road foundation structure


Figure 18. Road subgrade (base level)

In Turkish forestry, no improvement (to increase bearing capacity) is generally made to the ground and subgrade. The reason is to utilize the natural ground's inherent bearing capacity and reduce construction costs as much as possible. While this behavior is not a problem for rocky ground, for soil ground, the road prism is modified, and the majority of the road platform is left on the excavation side, attempting to utilize the natural ground formation (Eker and Acar, 2001).

Cut shaping:

After the excavated material is transferred to the fill side and the road's base and subbase layers are formed, the excavation slope is constructed. The excavation slope is angled according to the rock, mud, and soil conditions. Recently, excavation slopes have been excavated and angled mostly using excavators. An angle of less than 30° to the vertical axis is sought in rocky soils, 45° to mud soils, and 70° to soil. Depending on the ground conditions (type and slope angle, etc.), grader blade is used to form of cut slope shaing (Figure 19).


Figure 19. Leveling excavation slopes with a grader

Surfacing and shaping:

Roads to be used as raw dirt roads are graded using graders after the excavation and filling work, along with the alignment of the excavation slopes. Leveling can sometimes be done before the ditches are opened, and sometimes after they are constructed (Figure 20).

Figure 20. Surfacing and shaping for poad platform

Ditch forming:
Depending on the equipment used in conjunction with the excavation slopes, ditches are also constructed for drainage (Figure 21). In Türkiye, ditch widths are typically 1 m. A ratio of 1/3 is used for ditch slopes to ensure a good angle with the road platform (GDF, 2008).


Figure 21. Ditch forming with excavator after road surfacing

Stabilization with gravel:
The majority of forest roads in Türkiye are unpaved dirt roads. However, in recent years, with the increase in forest road density, the relative decrease in new roads, the widespread use of construction equipment, and the increased sales of standing timber, along with the need to improve road standards for long-length log transport, so stabilization is now being implemented as a superstructure project on forest roads. Stabilization materials are typically derived from natural materials (raw aggrega) at the site of road construction or from gravel, obtained after crushing these materials with crushers. Stabilization is achieved through mechanical compaction with construction machines or rarely cylindier (road roller).

4.5. Road Drainage - Hydraulic structures (The state of the art)
After the road's rough construction is completed, it's recommended to wait for the rainy season before opening it to traffic. During this process, water movements occurring in the road platform, excavation, and fill building are monitored to determine where and what type of hydraulic structure will be constructed to drain the water. Various hydraulic engineering structures are used to drain water that reaches and accumulates on the road surface. The first of these is the culverts. The culverts are pipes, usually round in cross-section, with diameters of 40-80 cm, and can slope between 4-8% from the excavation to the fill side. They can be made of concrete, reinforced concrete, steel, or plastic/pvc. Concrete walls and drain beds are constructed on the upstream and downstream sides to ensure safe water drainage.

Concrete, reinforced concrete, and lean concrete wide culverts can also be used instead of culverts wider than 80 cm, taking into account rainfall, the amount of water that will accumulate on the road surface, and the amount of sediment likely to be transported. The wide-culverts can have round/pipe, box, or basket-handle cross-sections. In cases where forest roads cut off shallow water sources/streams or when passing through seasonal shallow stream beds, fords are made so that water can be transferred from the forest road surface to the filling side in a safe and harmless manner. Wooden, concrete or steel bridges are also built to ensure traffic safety at stream crossings.

5. RESULTS AND DISCUSSSION

Despite developing technology and the use of modern machinery, it has been determined that various problems can be encountered at every stage of both the construction and lifespan of forest roads in Türkiye, as elsewhere in the world. For example, problems in the planning process include;

- Land topography (terrain, ground type, slope, disability)
- Stream density and stream crossings
- Distribution of the road to the area to the road spacing
- Areas not opened up (despite sufficient road density)
- Northern aspects
- Landslide areas
- Property or negative cardinal points crossing issues.

On the other hand, problems encountered during the application and project pratices (route design) phase;

- Lack of large-scale maps of all forest lands
- Field survey such as UAVs are not yet effectively used
- Obligation to comply with road slope limits (2-12%)
- Difficulties in route drawing in stream crossings
- Difficulty in crossing the zero line on high terrain slopes
- Inability to draw a road with a single slope in steep and mountainous terrain
- Inability to balance excavation and filling areas in steep and mountainous terrain
- Continuous excess excavation material
- Difficulty in placing curve due to radius limits
- Excess excavation and filling volume due to placing curve on the map
- Inability to estimate land ground properties (lack of geomorphology map)
- Soil surveys are not yet done at the project stage
- Excavation and filling amounts do not reflect the application due to underground ground changes

Furthermore, there are also several challenges and limits that complicate road construction and increase costs due to increased excavation and fill requirements. These can be summarized and listed as follows:

- Excessively steep terrain
- Heavy rock excavations
- Rock blasting
- Rock bluffs
- Stony terrain
- Karst ground
- Unstable soil ground
- Steep slope
- Reverse slope
- Stream crossings

-Road longitudinal slope
-Slope fortifications

Direct and indirect environmental impacts of forest roads (Eker, 2023) manifest themselves in varying amounts and intensities along forest road segments. The most significant direct environmental impacts include loss of productive forest land due to forest road construction, surface erosion caused by excavation and filling construction and inadequate drainage, runoff from excavation and filling slopes, and rock and rockfall. For example; in order to construct secondary forest roads on a stable platform and to avoid the negative environmental impacts of filling and excavation slopes, an average of 20 m is theoretically worked within the construction area (clearing witdh) (GDF, 2008; Eker and Ada, 2011). Accordingly, the total construction area (which is called as loss of forest area due to roads) within the forest land for standard forest roads with a theoretical construction width of 20 m is 24.000-48.000 ha. This means that between 1.2-2.8 percent of Türkiye's forest area is occupied by standard forest roads (Eker, 2023).

However, many environmental impacts related to road network such as habitat fragmentation, wind corridors, road edge effects, and human/vehicle traffic in deep forests that can trigger forest fires, are only just beginning to be addressed (Eker et al., 2010). Meanwhile, the undeniable role of forest roads, particularly in combating forest fires, is attracting the attention of both forest administrations and the public, with the aim of increasing road density and expanding the areas opened up to road operations.

Conducting ground surveys, performing technical and financial calculations based on field data, and initiating major repair and maintenance projects have been significantly improved forest road construction in Türkiye. Significant improvements have also been made in the last 20 years with the widespread use of excavators to prevent or at least mitigate direct damage during road construction. This has reduced both the construction and use costs of forest roads, reduced environmental impacts to acceptable levels, and enhance their functionality. For example; less area was damaged (22.16 %) on the road constructed with an excavator than a bulldozer, and the amount of lost area was 26.54 % less (Tunay, 2006). With all this, it can be suggested that Turkish forestry-specific guides for forest roads, such that:

- Determination and implementation of road standards according to traffic load
- Trying to keep road longitudinal slopes below 10%
- Regulating the distribution of roads on the field to optimize the relationship between road density and the rate of opening to operation
- Regulating the dimensioning, construction material and number for engineering structure needs
- Developing functional road network plans for new roads
- Utilizing sensitive data sources for planning and also project design (UAV, LIDAR)
- Utilizing spatial decision support systems (GIS) and optimization tools in planning and designing alternative road projects
- Passing roads from south (sunny) aspects
- Using excavators for environmentally sensitive road construction
- Ensuring slope stabilization by increasing excavation slopes
- Maintenance of ditches
- Completion and maintenance of drainage structures

REFERENCES

Acar, H. H., Eker, M. 2001a. Ormancılıkta Karar Verme Süreçlerinde Orman Yol ve Üretim Planlarının Değerlendirilmesi. Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi, 2(1):67-74.

Acar, H.H., Eker, M. 2001b. Excavator using for the forest road construction at step terrain and its case in Turkey. Proceedings of Third Balkan Scientific Conference, Volume 5, Bulgaria, pp. 257-268.

Acar, H.H., Eker, M. 2003. Orman yolu yapımında ekskavatörlerin kullanılması ve çevresel açıdan yararları. Batı Akdeniz Ormancılık Araştırma Müdürlüğü Dergisi. 5: 98-128

Akay, A.E., Sessions, J. 2004. Roading and Transport Operations. In Encyclopedia of Forest Sciences, J. Burley, J. Evans, and J. Youngquıst, Editors. Elsevier Academic Press: Amsterdam, etc. p. 259-269.

Akay, A.E., Sessions, J. 2005. Applying the decision support system, TRACER, to forest road design. Western Journal o f Applied Forestry. 20(3):184-191.

Akay, A.E. 2006. Minimizing total costs of forest roads with computer-aided design model. Academy Proceedings in Engineering Sciences (SADHANA). 31 (5): 621-633.

Akay, A. E., Serin, H., Sessions, J., Bilici, E., Pak, M. 2021. Evaluating the effects of improving forest road standards on economic value of forest products. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering, 42(2):245-258.

Bayoğlu, S. 1997. Orman Transport Tesisleri Ve Taşıtları (Orman Yolları). İ.Ü. Orman Fakültesi Yayın No: 3969/434, ISBN 975-404-430-9, İstanbul.

Demir, M., Hasdemir, M., 2005. Functional planning criterion of forest road network systems according to recent forestry development and suggestion in Turkey. Am. J. Environ. Sci, 1(1):22-28.

Dykstra, D.P., Heinrich, R. 1996. FAO Model code of forest harvesting practice. FAO Forestry Department. Rome, 87 p.

Eker, M., Ada, N. 2011. Orman yolu kalite analizine yönelik ölçüt ve gösterge setinin oluşturulması. Süleyman Demirel Üniversitesi Orman Fakültesi Dergisi, 12(2): 89-97

Eker, M. 2023. The Possible Effects of Forest Roads in Terms of Sustainable Forestry. Sustainable Approaches in Forestry Edited by Gökhan ŞEN, Ersin GÜNGÖR. Duvar Publishing, pp: 96-124.

Erdaş, O. 1997. Orman Yolları – Cilt:I, KTÜ Orman Fakültesi Yayınları No:187/25, 391 s., Trabzon.

Erdaş O., Acar H.H., Eker M. 2014. Orman Ürünleri Transport Teknikleri, KTÜ Yayın No:233, Orman Fakültesi Yayın No:39, 504 s. Trabzon.

GDF, 2008. Orman yolları planlaması, yapımı ve bakımı, Tebliğ No: 292 (Communique No:292 – Planning, Construction, and Maintenance of Forest Road), General Directorate of Forestry of Türkiye, 338 p., Ankara.

GDF, 2025. Forestry Statistics 2024. Official Statistics. General Directorate of Forestry, Ministry of Agriculture and Forestry. https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler Access: 15 May 2025.

Gümüş, S., Acar, H. H., Toksoy, D. 2008. Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. Environmental monitoring and assessment, 142, 109-116.

IUFRO, 2025. About the Working Party, Working Party 3.01.02 Road engineering and management. https://www.iufro.org/divisions/30000-forest-operations-engineering-and-management/30100-harvesting-and-transportation-engineering/30102-road-engineering-and-management Accessed 12 April 2025

Papagiannakis, A.T., Masad, E.A. 2024. Pavement design and materials. John Wiley & Sons., 656 p.

Tunay, M. 2006. The assessment of environmentally sensitive forest road construction in Calabrian pine forest areas of Turkey. Journal of Environmental Biology/ cademy of Environmental Biology, 27(3):529-535.

Winkler, N. 1999. Environmentally sound forest infrastructure development and harvesting in Bhutan, FAO Forest Harvesting Case Study 12, Rome, 68-70.

Investigation the Changes in the Amounts of $PM_{2.5}$, PM_{10} and CO_2 in Cutting Operations in Harvesting Areas

Ebru Bilici[1*], Tolga Öztürk[2]

[1*]Giresun University, Dereli Vocational School, Giresun, Türkiye
[2]Istanbul University-Cerrahpasa, Faculty of Forestry, Department of Forest Engineering, Istanbul, Türkiye
*ebru.bilici@giresun.edu.tr

Abstract

Growing population in Türkiye increases demand for wood materials. Despite increased mechanization, the preference for chainsaw use in the cutting phase remains high. Since this still involves labor-intensive work, it is important to reduce risk factors in terms of worker health and safety. When cutting is carried out with a chainsaw, many air pollutants such as bark residues, dust, sawdust, fuel material, etc. are expelled into the environment. This situation reduces the air quality for the workers and environment. This study aims to investigate the impact of the cutting process on worker health and environmental impacts in stone pine (*Pinus pinea* L.) plantations in Sarıyer region. The air pollution parameters $PM_{2.5}$, PM_{10}, CO_2 and HCHO levels during the cutting process were measured using a Temtop M2000 air quality meter. The results showed that when comparing these values to standard air quality metrics, it's clear that the peak values of $PM_{2.5}$, PM_{10}, and CO_2 result in a "Unhealthy" environment. The average values for all three are classified as "Unhealthy" for $PM_{2.5}$, and "Moderate" for PM_{10} and CO_2. Based on the identified results, risk factors need to be determined, and corresponding measures must be taken. In this context, the use and design of personal protective equipment is significant. Updates to designs and information dissemination need to be carried out based on risk factors. There is also a need to raise awareness and provide training for forest workers on the use of protective equipment. These findings could inform policies on worker health and environmental air quality in wood production.

Keywords: *Harvesting, Cutting, Air quality, Timber, Temtop M2000.*

1. INTRODUCTION

Raw wood production requires substantial time in forestry operations. The process involves multiple specialized stages, each needing specific methods and skills. These stages include felling, delimbing, crosscutting, extraction, stacking, loading, transportation, and unloading (Gülci et al., 2017; Öztürk et al., 2024). In Türkiye, these operations utilize an integrated approach combining both manual labor and mechanical equipment. The extraction phase employs a combination of mechanical equipment, including tractors and skyline systems, supplemented by manual labor as needed.

The transition to mechanized forestry work also brings some health risks to the workers working in wood production works. These factors, which pose a risk to human health and are mostly encountered by workers working in the forest, can be diversified as noise, waste gases, particulate matter, vibration, etc. (Taş and Akay 2022). Tree harvesting operations present significant operational challenges, requiring careful attention to safety protocols and resource allocation. The process demands consideration of not only operational ergonomics but also environmental conditions, particularly air quality parameters. Of specific concern is the elevation of $PM_{2.5}$ and PM_{10} particulate matter levels, which can affect operator respiratory conditions. Operators working in debarking and cutting operations are exposed to this dense mixture when they do not use protective equipment. Exposure to wood dust in long-term work can cause asthma, lung cancer, skin and eye irritations, runny nose (Gülci et al., 2018), upper respiratory and lower respiratory tract disorders (Bishop 2021), poisoning, and allergies in the respiratory system (Arslan et al., 2010).

Particulate matter (PM), a common air pollutant, is a mixture of solid and liquid organic and inorganic matter suspended in the air. Particles vary in origin, chemical composition, and size. Size is defined as aerodynamic diameter and ranges from 0.001 to 100 μm. Particles are generally characterized as coarse (2.5-10 μm), fine (0.1-2.5 μm), and ultrafine (≤0.1 μm) (Gao et al., 2015). Coarse particles are referred to as PM_{10}, fine particles as $PM_{2.5}$, and ultrafine particles as PM_1. Particles referred to as PM_{10} can reach the upper respiratory tract in humans, while particles referred to as $PM_{2.5}$ can affect human health by reaching the lower respiratory tract (Arslan et al., 2010).

This research initiative focused on quantifying $PM_{2.5}$, PM_{10}, and CO_2 concentrations during coniferous tree harvesting operations. The study documented changes in air composition during the cutting process. Based on these findings, it offers practical recommendations for managing air quality in forest harvesting operations.

2. MATERIAL AND METHODS

2.1. Material

This study was carried out in compartment number 152 located within the boundaries of Kurtkemeri Forest Management Directorate of Istanbul Regional Directorate of Forestry in Türkiye. Kurtkemeri Forest Management Directorate covers a total area of 2832 ha, including 2690 ha forested and 142 ha open area. The region is located between 41º 14′24" – 41”09′29"north latitude and 28º57′19" – 28º53′26" east longitude (GDF 2023) (Figure 1). The size of compartment number 152, where the study was conducted, is 25 ha. The area cut in the compartment is stone pine (*Pinus pinea* L.) plantation areas.

The study was conducted between June 2024 and July 2024. Two workers were involved in the cutting of the trees (Figure 2). The Tamtop device is placed in the area close to the shoulder of the cutting worker. The section closest to the breathing area was chosen so that the worker would not be disturbed during the work. The average slope of the land within the compartment varies between 2-18%. There is a middle dense ground cover in the cutting compartment. The logs were removed from the compartment to the roadside landing with the help of a tractor, and the loading process was carried out on the roadside. 3 m logs and 1.25 m industrial timber are the products produced in the compartment. During the study, the humidity of the air was 45% and the wind speed varied between 0 and 3 km/h.

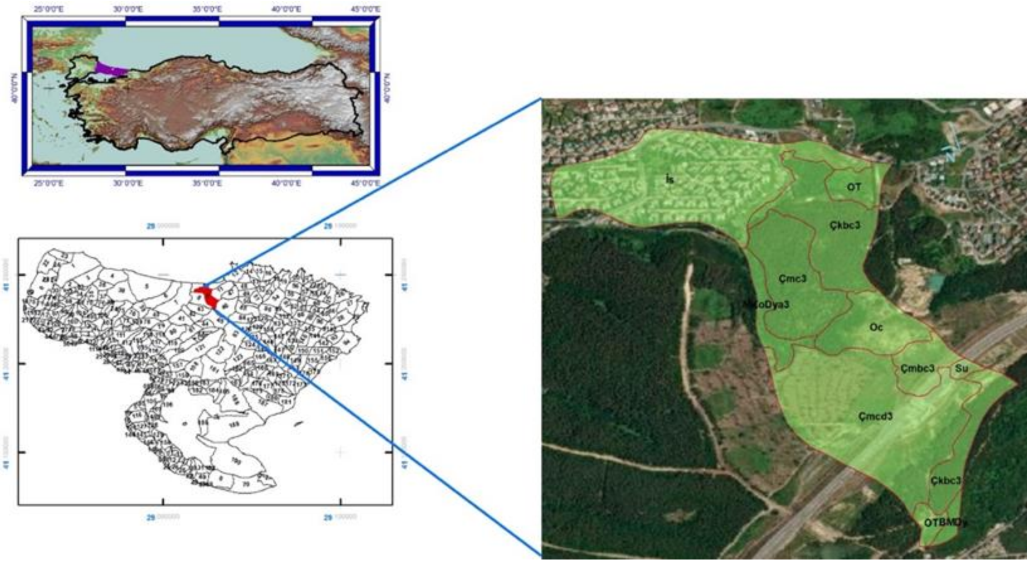


Figure 1. Study area

2.2. Metod

In the study, Echo CS 621 chainsaw was used to cutting operations. The technical specifications of the chainsaw are shown in Table 1. Temtop M2000 air quality meter (Figure 2 and Figure 3) is a $PM_{2.5}$, PM_{10}, formaldehyde, CO_2, humidity, and temperature meter. General technical specifications of the device are shown in Table 2.

Table 1. Technical specifications of Echo CS 621 chainsaw (URL-1)

Technical specifications	Unit	Technical specifications	Unit
Cylinder volume (cm^3)	59.8	Bar length (cm)	50
Power output (kW)	3.3	Weight (kg)	6.2
Tank capacity (l)	0.64	Chain pitch	3/8"
Oil depot (liter)	0.30	Sound pressure level (dB)	101.6
Chain speed (m/h)	20.7	Sound power level (dB)	113.4
Max. Rotation speed (rpm)	12 500	Equivalent vibration level (m/s^2)	5.2

Figure 2. Cutting work and worker

Figure 3. Temtop M2000

Table 2. Technical specifications of Temtop M2000

Technical Specifications	Measuring Ranges
M2000 model	For $PM_{2.5}$;
TFT Color LCD screen	-Measuring range: 0 – 999 µg/m^3
Battery voltage: 3.7 VDC	-Resolution: 0.1 µg/m^3
Dimension: 73.5 x 220 x 37.5 mm	For PM_{10};
Data transfer: USB	-Measuring range: 0 – 999 µg/m^3
Temparature range: 0 – 50 °C	-Resolution: 0.1 µg/m^3
Humidity range: %0-90	For CO_2;
Atmospheric pressure: 1 atm	-Measuring range: 0 – 5000 PPM
Output voltage: 5 VDC	-Resolution: 1 PPM
Output current: 1 A	For Formaldehyde (HCHO);
Rechargeable	-Measuring range: 0 – 5 mg/m^3
	-Resolution: 0.001 mg/m^3

There are limit values arranged in tables for air quality, which is very important for human health. When these limit values are exceeded, permanent problems for human health may arise. These limit values are shown in Table 3 (Flores et al., 2020).

Table 3. Air quality limit values

<table>
<tr><th>$PM_{2.5}$</th><th>PM_{10}</th><th>CO_2</th><th>Status</th><th>HCHO</th><th>TVOC</th><th>Status</th></tr>
<tr><th>µg/m^3</th><th>µg/m^3</th><th>ppm</th><th>Status</th><th>mg/m^3</th><th>mg/m^3</th><th>Status</th></tr>
<tr><td>0.0-12.0</td><td>0-54</td><td>0-700</td><td>Good</td><td>0-0.1</td><td>0-0.5</td><td>Safe</td></tr>
<tr><td>12.1-35.4</td><td>55-154</td><td>701-1000</td><td>Moderate</td><td rowspan="5">>0.1</td><td rowspan="5">>0.5</td><td rowspan="5">Unsafe</td></tr>
<tr><td>35.5-55.4</td><td>155-254</td><td>1001-1500</td><td>Unhealthy for sensitive groups</td></tr>
<tr><td>55.5-150.4</td><td>255-354</td><td>1501-2500</td><td>Unhealthy</td></tr>
<tr><td>150.5-250.4</td><td>355-424</td><td>2501-5000</td><td>Very unhealthy</td></tr>
<tr><td>>250.4</td><td>>424</td><td>>5000</td><td>Hazardous</td></tr>
</table>

PM_{10} (≤10 µm) from dust and construction, causing respiratory irritation; $PM_{2.5}$ (≤2.5 µm) from vehicle exhaust and wildfires, penetrating deep into the lungs; PM_1 (≤1 µm) from similar sources as $PM_{2.5}$, infiltrating cells and posing severe health risks (California Air

Resources Board, 2024). Different substances such as gas, vapor, smoke, and fog pollute the air of the working environment. When these substances reach high concentrations, they become harmful to human health (Taş and Akay 2022). Carbon dioxide (CO_2), whose rate in the air is quite low compared to other gases, is currently around 400 ppm in the atmosphere. However, CO_2 levels in the atmosphere tend to increase rapidly due to the greenhouse effect (Müezzinoglu, 2000). It is a non-flammable, colorless, and odorless substance resulting from natural inhalation and combustion. CO_2 gas, which can be released into the air as a result of the combustion reaction of all kinds of organic matter, is present in the content of waste gases released into the air by domestic heating, exhaust gases, industrial plants, and power plants. Although CO_2 is non-toxic, it reduces the amount of available oxygen in the environment and causes suffocation due to lack of oxygen. When the CO_2 level in the environment exceeds 3500 ppm, negative health effects are observed on the nervous system with breathing difficulties (Menteşe and Çotuker 2021).

In this study, the amounts of $PM_{2.5}$, PM_{10}, and CO_2 in the cutting process of coniferous trees in wood production studies were measured. After the measurements were taken in the field, the examinations were carried out in two steps in the office stage. First, the values related to air quality were examined and evaluated. The frequency distribution of the values was analyzed and their situations were examined according to the variables. In the second step, the relationship between diameter and height was examined with the variables and the relationship between the variables was evaluated with correlation analysis.

3. RESULTS

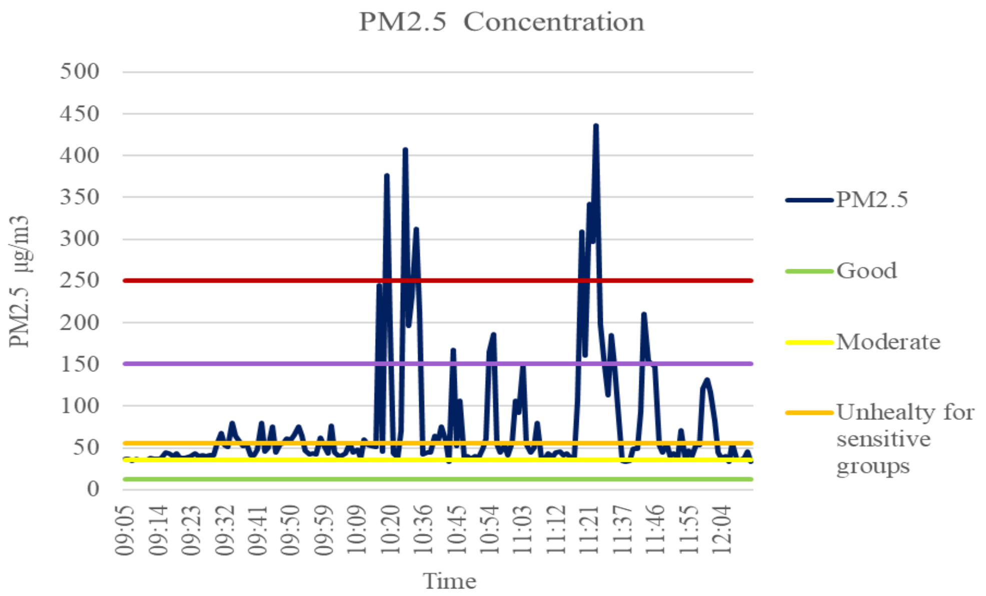
Descriptive statistical information of the measurements obtained because of the measurement values and calculations made with the Temtop M2000 air quality device are given in Table 4.

Table 4. Statistical variables

Variables	**$PM_{2.5}$**	**PM_{10}**	**CO_2**	**HCHO**	**$d_{0.5}$ (cm)**	**H (m)**
Mean	184.6944	235.9183	616.2777	0.010441	22.25	7
Std.Error	30.18746	38.02493	17.91347	0.001664	0.780	0.189
Median	75.25	89.25	580.5	0.006	23	7
Mode	50.33333	53	508	0.001	27	6
Std.Deviation	215.5816	271.5523	127.9277	0.01188	5.570	1.349
Sample Variance	46475.43	73740.65	16365.51	0.00014	31.03	1.82
Kurtosis	0.818845	0.562535	10.91579	4.21511	-1.316	-0.7566
Skewness	1.527670	1.452368	2.629124	2.01136	-0.084	-0.1653
Range	689.25	845.5	783.75	0.0545	19	5.5
Minimum	36.5	44	464.5	0.001	13	4.5
Maximum	725.75	889.5	1248.25	0.0555	32	10
Sum	9419.416	12031.83	31430.17	0.5325	1135	357
Count	51	51	51	51	51	51

$d_{0.5}$: Mid diameter *cm*, *V:* Timber volume *(m^3)*, *c:* Circumference (*m*),
S: Debarking surface area (m^2), *Bv*: Bark volume (m^3), *$PM_{2.5}$*: Particulate matter of size 2.5 microns and smaller, *PM_{10}*: Particulate matter of size 10 microns and smaller,
CO_2: Carbondioxide, *HCHO*: Formaldehyde,

When the international air quality limit values given in Table 3 are compared with the values found as a result of the measurements; it is found that the maximum values of $PM_{2.5}$, PM_{10} and CO_2 (725,75 μg/m^3, 889,5 μg/m^3 and 1248,25 ppm) constitute a “Hazardous and Unhealty” environment, while the average values for all three values (184,69 μg/m^3,235,91 μg/m^3 and 616,28 ppm) are "Unhealty" for $PM_{2.5}$ and "Moderate" for PM_{10} and "Moderate" for CO_2. The HCHO value was determined to be safe throughout all measurements so as not to pose a risk to human health. The graphs show changes in values during the measurement period. Here we have the opportunity to observe the durations during which the worker is exposed to dangerous levels. For $PM_{2.5}$, the worker is exposed to dangerous levels between 25-45 minutes (Figure 4).



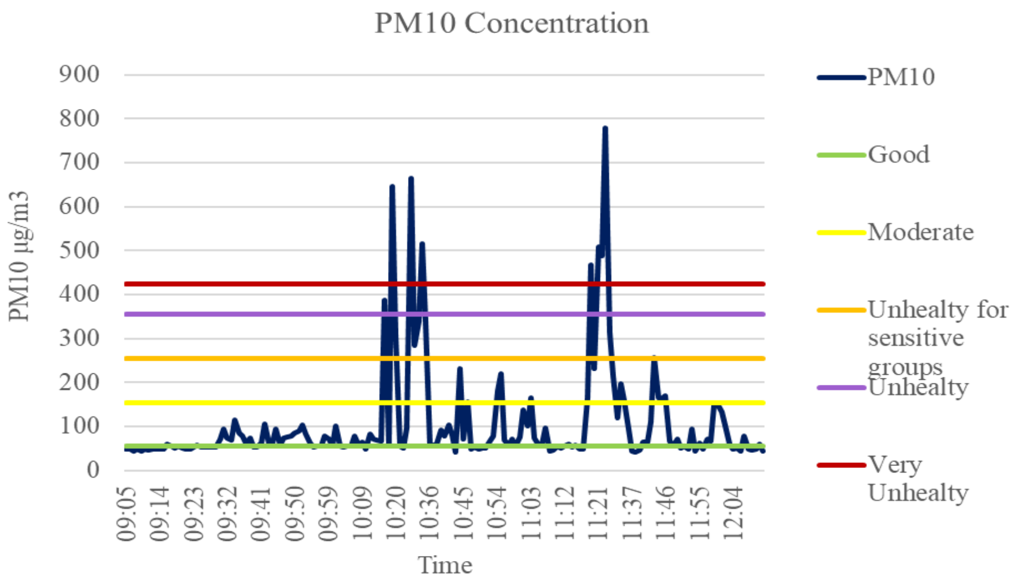
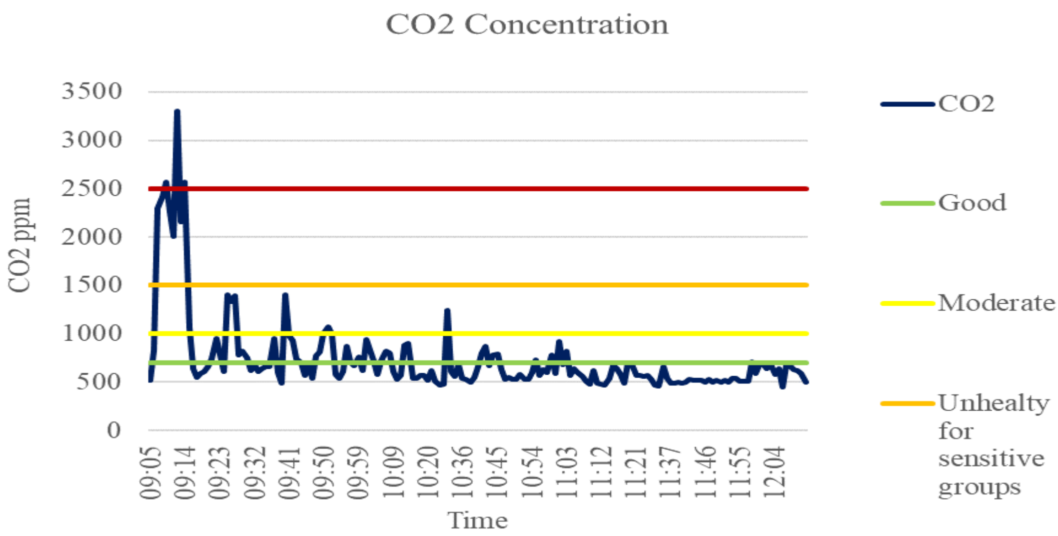


Figure 4. Variation of $PM_{2.5}$, PM_{10} concentrations by exposure time

CO2 was observed to be exposed to unhealthy levels during an approximately 8-minute period. This is thought to be due to the operation of the chainsaw. The formaldehyde value did not reach any dangerous level (Figure 5).



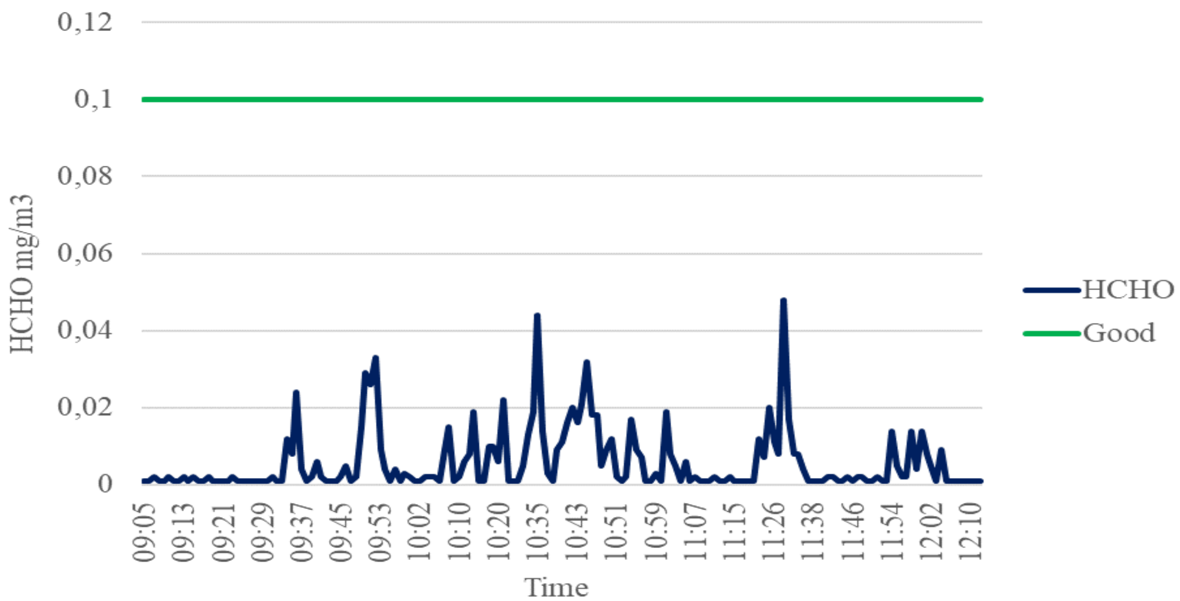


Figure 5. Variation of CO_2, and HCHO concentrations by exposure time

The frequency distribution, which shows how often the measurement results occur within specific ranges for each variable, is displayed. Accordingly, it is observed that $PM_{2.5}$ values predominantly fall within dangerous levels in terms of air quality (Figure 6). Dimou et al. (2020) examined forest workers' exposure to wood dust during log cutting operations in production areas. Based on 2017 hardwood limit values (3 mg m−3) (Directive (EU) 2017/2398), their study found that half of the sampled loggers (50% - 8 of 24) experienced dust exposure exceeding EU OEL standards.

Figure 6. The frequency distribution of $PM_{2.5}$, PM_{10} and CO_2 concentrations

When the analysis results based on the obtained data are examined, a very weak relationship was detected between diameter and height values and the variables. (Table 5). There is a weak positive correlation between carbon dioxide and $PM_{2.5}$ and PM_{10}. When examining the relationships between the variables themselves, a very high correlation was found between $PM_{2.5}$ and PM_{10}.

Table 5. Correlation analysis

	$PM_{2.5}$ (µg/m^3)	**PM_{10} (µg/m^3)**	**CO_2 (mg/m^3)**	**HCHO (mg/m^3)**	**d_(0.5) (cm)**	**H (m)**
$PM_{2.5}$	1	0,986376	0,181725	0,588841	-0,02681	0,0189
PM_{10}	0,986376	1	0,194118	0,561228	-0,0329	0,044009
CO_2	0,181725	0,194118	1	0,182575	0,22771	0,212481
HCHO (mg/m^3)	0,588841	0,561228	0,182575	1	-0,10012	-0,14797
d_0.5 (cm)	-0,02681	-0,0329	0,22771	-0,10012	1	0,791707
H (m)	0,0189	0,044009	0,212481	-0,14797	0,791707	1

Biocca et al., (2023) examined the air-borne particle size distribution of wood dust emitted during small-scale forestry operations. The relationship between chainsaws and particulate matter was examined in different working time and summer trials showed a significant difference between chainsaw types, with endothermic models producing 20% more particles than electric ones. Particle count analysis showed dust production varied by treatment.

4. CONCLUSION

Air quality directly affects worker health, and long-term exposure is critically important for worker health. High concentrations of particulate matter ($PM_{2.5}$, PM_{10}) and gas pollutants (CO_2, HCHO) increase respiratory diseases and long-term health risks. Although this risk is considered low because forestry activities are carried out in open environments, the study results have shown that there are exposure durations at levels that will affect worker health due to the work performed. During these cutting activities, measurements were made with Temtop M2000 air quality meter.$PM_{2.5}$, PM_{10}, CO_2 and HCHO values were measured throughout the cutting process and various values were found. Considering these values, it was determined that the average value of $PM_{2.5}$ is an “Very Unhealthy” environment when compared to international threshold values. The average values of PM_{10} and CO_2 were found to be “Unhealty for sensitive persons” and “Good”, respectively. The average value of HCHO was found to be “Safe”.The high $PM_{2.5}$ value indicates that particles of 1.0-2.5-micron size are dense in the environment and these particles may cause various disorders, especially in the lower respiratory tract of worker.

According to the obtained results, certain measures need to be taken to reduce exposures and consequently harm. Workers must wear masks suitable for $PM_{2.5}$ and PM_{10} particles during cutting operations, along with standard protective gear (glasses, hard hats, gloves, pants). The scheduling of field work durations significantly affects exposure. At this stage, no matter how much personal protective equipment is used, it remains an important step that requires attention. Increase rest periods during intensive work to allow airborne particles to settle. Regular medical check-ups focusing on respiratory health are essential.

REFERENCES

Arslan, S., Aybek, A., Ekerbiçer, H.Ç., 2010. Measurment of Personal PM_{10}, $PM_{2.5}$ and PM_1 Exposures in Tractor and Combine Operations and Evaluation of Health Disturbances of Operators. Journal of Agricultural Sciences, 16: 104-115.

Biocca M, Pochi D, Gallo P, Fanigliulo R.2023. Air-borne particle size distribution of wood dust emitted during small scale forestry operations. J Basic Appl Sci 2023; 19: 60-67.

California Air Resources Board., 2021. Inhalable Particulate Matter and Health ($PM_{2.5}$ and PM_{10}). , A.S., Ward, A.M., Ruiz, M., 2020. The Intersection Between the Dwelling Environment and Health and Wellbeing in Impoverished Rural Puebla, Mexico. LASA2020 Virtual Congress of the Latin Amercan Studies Association, May 13-16, Mexico.

Dimou, V., Malesios, C. & Chatzikosti, V. Assessing chainsaw operators’ exposure to wood dust during timber harvesting. SN Appl. Sci. 2, 1899 (2020). https://doi.org/10.1007/s42452-020-03735-6

Directive (EU) 2017/2398 of the European Parliament and of the Council of 12 December 2017 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work.

Gao, G., Sun, F., Thao, N.T.T., Lun, X., Yu, X., 2015. Different Concentrations of TSP, PM_{10}, $PM_{2.5}$ and PM_1 of Several Urban Forest Types in Different Seasons. Pol. J. Environ. Stud., 24(6): 2387-2395.

GDF., 2023: Sarıyer Orman İşletme Şefliği Amenajman Planı, İstanbul.

Gülci, N., Akay, A.E., Erdaş, O., 2017. Productivity Assessment of Alternative Timber Debarking Methods. Sumarski List, 9-10: 469-476.

Gülci, S., Akay, A.E., Spinelli, R., Magagnotti, N., 2018. Assessing the Exposure of Chipper Operators to Wood Dust in a Roadside Landing Area. Fresenius Environmental Bulletin, 27(6): 4132-4138.

Menteşe, S., Çotuker, O., 2021. Partikül Madde, Karbon Monoksit ve Karbondioksit Seviyelerinin İç ve Dış Ortamlarda Değişimi. Mühendislik Bilimleri ve Tasarım Dergisi, 9(3): 723-734.

Müezzinoğlu, A., 2000. Hava Kirliliğinin ve Kontrolünün Esasları. Dokuz Eylül Yayınları. İzmir.

Öztürk, T., Bilici, E., İnan, M., Yer, B.M., 2024. Examining the Changes in the Amounts of $PM_{2.5}$, PM_{10} and CO_2 in the Environment in Debarking Operations. Sumarski List, 11-12: 555-564.

Taş, İ., Akay, A.E., 2022. Evaluation of Various Risk Factors Caused by Mechanized Equipment Used in Forest Operations. Eur. J. Forest Eng., 8(1): 40-45.

URL-1. https://www.echo-turkiye.com/tr_tr/%C3%BCr%C3%BCnler/motorlu-testereler/motorlu-testere/cs-510_37/ (Data accessed: 25.07.2025)