Indonesian Journal of Community Engagement
Jurnal Pengabdian kepada Masyarakat
Vol. 11, No. 2, June 2025, Page. 72-76
DOI: http://doi.org/10.22146/jpkm.100828

Mapping Above-Ground Mangrove Ecosystems for Nature Tourism Routes to Support Sustainable Tourism Development in South Lembar Village, West Nusa Tenggara

Muhamad[1]*, Djarot Heru Santosa[2], Endah Nurhawaeny Kardiyati[3], Mohammad Alief Rizky Putra[4]

[1]Master Program of Tourism Studies, Graduate School, Universitas Gadjah Mada, Yogyakarta, Indonesia
[2]Department of Language and Literature, Faculty of Cultural Sciences, Universitas Gadjah Mada, Yogyakarta, Indonesia
[3]Faculty of Social and Political Sciences, Universitas Muhammadiyah Cirebon, Indonesia
[4]Study Program of Forestry, Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia

Submitted: October 18st 2024; Revised: March 19th 2025; Accepted: May 21st 2025

Keywords:
Above-ground mangrove ecosystems
Nature tourism routes
Sustainable tourism development
Climate change

Abstract This study employed a multifaceted approach to map and quantify the above-ground carbon (AGC) content of mangrove forests using multispectral data analysis. The scoring method involved assigning values to various parameters based on their landscape characteristics. The research was conducted at beach locations in South Lembar Village and Lembar Village. Fieldwork took place in mangrove areas from July to August 2024. Sampling locations were determined using a purposive sampling method, in which samples were selected based on specific landscape criteria. The study incorporated both primary and secondary data sources. Primary data were collected through in-situ measurements and sampling, while secondary data were obtained from literature reviews and relevant institutional databases. The Random Forest (RF) classification method demonstrated high efficacy in identifying mangrove ecosystems, achieving an overall accuracy (OA) of 0.968 and a Kappa coefficient of 0.918. These metrics indicate strong agreement between the classification results and ground truth data. The analysis revealed that mangrove ecosystems covered approximately 50.08 hectares in the study area, indicating significant potential for ecotourism development, particularly for trekking routes. This study contributes to the understanding of mangrove ecosystem distribution and its potential for sustainable tourism development, particularly as climate change adaptation initiatives. The high accuracy of the mapping results provides a reliable basis for informed decision-making in environmental management and ecotourism planning. Further studies may be needed to assess the carrying capacity of these ecosystems and to develop strategies for their conservation alongside sustainable tourism practices. The mangrove area still requires overall landscape development, with assessment results showing an average score of 6.3, indicating moderate conditions and a need for improvement.

1. INTRODUCTION

Mangroves are trees with unique characteristics, combining features of both marine and terrestrial plants, notably their prominent root system known as pneumatophores. This root structure is an adaptation to oxygen-deficient or anaerobic soil conditions. Mangroves are a distinctive component of coastal vegetation, typically found in estuaries and deltas in sheltered tropical and subtropical regions (Mulyadi et al., 2010). Mangrove forests represent

ISSN 2460-9447 (print), ISSN 2541-5883 (online)
*Corresponding author: Muhamad
Graduate School, Universitas Gadjah Mada, Jl. Teknika Utara, Pogung, Sinduadi, Mlati, Sleman, Yogyakarta, 55284, Indonesia
Email: drmuhammad@ugm.ac.id

a type of forest that thrives in tidal zones, particularly along coastlines, with plant communities that exhibit high salt tolerance (Ario et al., 2016). The mangrove ecosystem consists of various species, including Rhizophora sp., Bruguiera sp., Avicennia sp., Xylocarpus sp., and Sonneratia sp. Mangrove trees demonstrate exceptional carbon sequestration capabilities. They absorb atmospheric carbon dioxide (CO_2) and store it in their stems, leaves, and roots. Through photosynthesis, mangroves capture CO_2 and convert it into biomass. Notably, mangrove forests are among the most carbon-rich ecosystems in the tropics, with an average carbon content of 1,023 MgC per hectare (Farista & Virgota, 2021). Studies have shown that mangroves can store three to five times more carbon than terrestrial tropical forests. Furthermore, mangrove forests emit less carbon into the atmosphere compared to terrestrial forests, partly because the decomposition of aquatic plant litter does not release carbon into the air.

Mangroves, along with other marine flora, play a crucial role in blue carbon sequestration. Coastal ecosystems such as mangrove forests naturally absorb carbon from both the atmosphere and the oceans, storing it over long periods. This stored carbon is referred to as "blue carbon" (Muzani et al., 2020). Mangroves store a significant portion of this carbon in their soil and below-ground structures, which are rich in organic matter and capable of sequestering carbon in thick soil layers for thousands of years. Indonesia has considerable potential for blue carbon sequestration through its coastal and marine ecosystems, particularly mangrove forests. The carbon stored in mangrove sediments tends to be more stable and less likely to be released into the atmosphere.

1.1 Mangroves capacity to mitigate global

According to Fitria (2021), global warming refers to the increase in Earth's surface temperature due to the greenhouse effect, primarily caused by carbon dioxide emissions from fossil fuel combustion and deforestation. Global warming affects life around the world by altering climate patterns and impacting all living organisms. The primary cause of global warming is the rising concentration of CO_2 in the atmosphere. Mangrove ecosystems play a crucial role in mitigating climate change through their capacity to absorb carbon dioxide, one of the major contributors to global warming. Located in coastal regions, mangroves have the potential to sequester approximately 138 million tons of carbon annually, equivalent to five times the carbon storage capacity of Indonesia's tropical forests. This indicates that mangrove ecosystems could reduce global carbon emissions by up to 25% (Muzani et al., 2020).

When mangrove ecosystems are deforested or degraded, the carbon that has been stored over thousands of years can be released back into the atmosphere, significantly increasing greenhouse gas emissions. Therefore, preserving mangrove forests is essential for maintaining ecosystem stability and sustaining their role in carbon sequestration. Conservation efforts help prevent further intensification of global warming by ensuring that the carbon stored in these ecosystems remains contained.

In addition to their ecological value, mangrove trees can also serve as an attraction for nature-based tourism. Mangrove forests have the potential to become educational tourism sites through activities such as mangrove planting and seedling cultivation. In the villages of Lembar and South Lembar, one form of ecotourism practiced is mangrove ecotourism. This form of tourism not only offers recreational and educational experiences but also contributes to climate change mitigation, disaster risk reduction in coastal areas, and local economic development. The root systems of mangrove forests help protect coastal soils by serving as natural barriers against erosion caused by water. These forests are typically found in muddy coastal areas filled with complex root structures that aid in breaking down organic waste transported to the shore.

2. METHOD

The research was conducted in Lembar Selatan Village, Lembar District, West Lombok Regency, West Nusa Tenggara. This village, which received third place in the 2023 Indonesian Tourism Village Award (ADWI), features extensive mangrove forest areas distributed along its western region. The mangrove areas in this village are divided into three zones: the Cemare coastal area, the

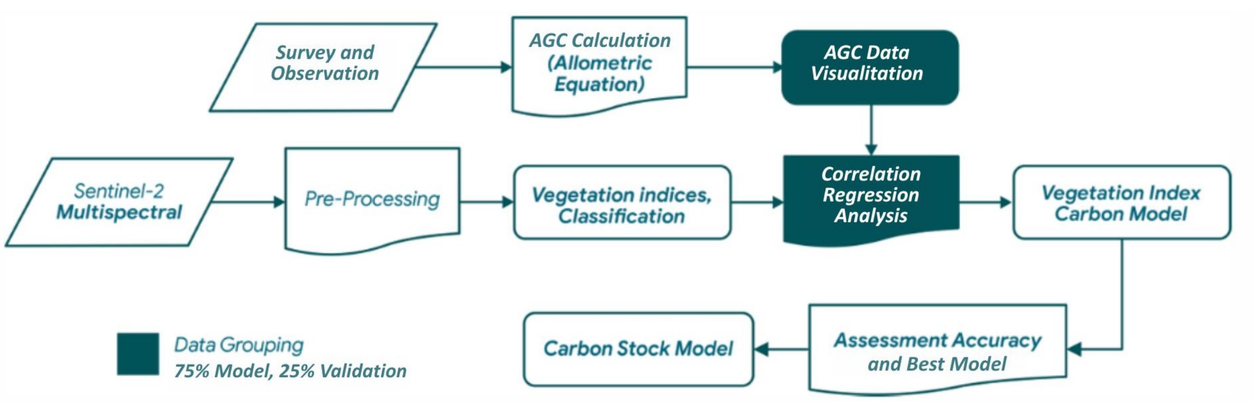

Figure 1 . Flowchart of the research methodology used for mapping and calculating AGC in mangrove forests (Suardana et al., 2023)

Sacred Tomb area, and the Mangrove Forest zone. This study utilized several data sources and tools, including: (1) satellite imagery data, (2) vector data (shapefile) representing the administrative boundaries of Lembar Selatan Village, and (3) a laptop with a Windows operating system. Google Earth Engine was used for processing image data, while ArcGIS Pro was employed to visualize the results. The mangrove forests in South Lembar Village and Lembar Village are distributed along the western coastline of South Lembar Village, with some areas extending toward the northern beach of Lembar Village, covering a significant portion of the coastal zone.

2.1 Data collection

Image data processing was conducted using Google Earth Engine (GEE). Field data collection was based on the methodology developed by Suardana et al. (2023)(Figure 1), who studied mangrove forests in Benoa Bay, Bali. In this study, 40 field points were selected. Of these, 30 points (75%) were used for model development, while 10 points (25%) were used for model validation.

The field points were established using a random sampling method and adjusted according to field conditions, particularly in terms of accessibility. Transect lines were drawn perpendicular to the coastline or river and extended inland. Mangrove species were identified using an ecological approach that considered the characteristics of each species and their respective growth zones.

The diameter at breast height (DBH) was measured at each plot for trees with a diameter of 10 cm or more, as these trees significantly contribute to above-ground biomass estimates. DBH measurements were taken at standard chest height, approximately 1.3 meters from the ground surface (Suardana et al., 2023).

3. RESULT AND DISCUSSION

3.1 Identification of mangrove species in South Lembar Village

The identification of mangrove species in zones near the Lembar Village ecosystem can be viewed as part of a succession process and reflects the ecosystem's response to external environmental factors. This condition arises from the role and adaptive capabilities of mangrove species in coastal environments.

Several mangrove species grow in the habitat area of Lembar Bay, representing three primary genera: Avicennia sp., Rhizophora sp., and Sonneratia sp. Avicennia sp. is commonly found in Cendi Manik Village and South Lembar Village, while Rhizophora sp. and Sonneratia sp. are more evenly distributed across the coastal areas of Lembar Bay (Rahman, 2022). According to information provided by local communities, South Lembar Village is home to nine mangrove species distributed along its western coastline. These species include Bruguiera gymnorhiza, Rhizophora mucronata, Avicennia marina, Sonneratia alba, Lumnitzera racemosa, Rhizophora apiculata, Ceriops tagal, Sonneratia caseolaris, and Nypa fruticans Wurmb.

This study focused on mangrove forests along the coast of South Lembar Village. The satellite imagery used was a cloud-free composite from Sentinel-2, covering the period from July to December 2023. The detected mangrove area in the study site was approximately 50.08 hectares. The classification of mangrove and non-mangrove areas using the RF method, based on several parameters, produced highly accurate results, with an OA of 0.968 and a Kappa coefficient of 0.918. The classification results derived from Sentinel-2 imagery demonstrated strong alignment with field observations, as reflected in the Kappa coefficient.

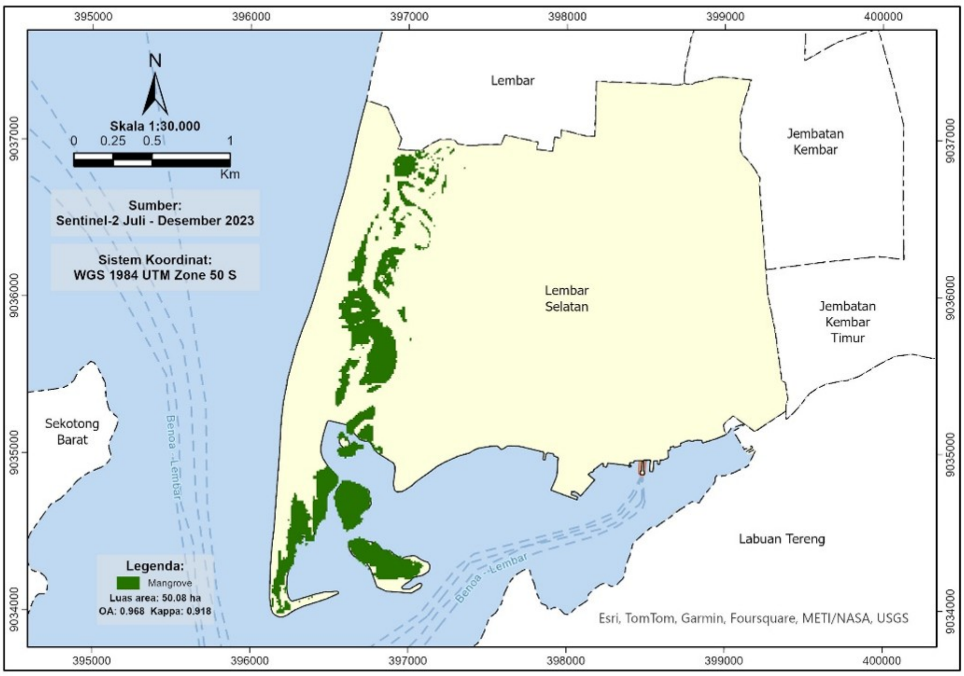

Figure 2 . Mangrove zoning pattern in Lembar Village

Figure 2 illustrates the mangrove zonation pattern as a horizontal distribution of vegetation extending from the shoreline inland in Lembar Village. The formation of this zonation is influenced by soil characteristics such as organic matter content, salinity, and groundwater conditions. These factors are, in turn, shaped by the relatively flat topography of the coastal area.

3.2 Above-ground carbon stock in the South Lembar coastal area

Carbon absorbed by plants is stored in the form of wood biomass. Therefore, the most straightforward method to increase carbon storage is by planting and maintaining trees (Arief, 1994). To maximize carbon sequestration potential, emphasis should be placed on increasing above-ground biomass rather than soil carbon, as the amount of soil organic matter is relatively smaller and tends to be less stable over time.

3.3 Mapping of mangrove carbon prediction

The model with the best performance—indicated by the lowest root mean square error (RMSE) and the highest correlation coefficient (r)—was used to estimate and map AGC values across the entire study area. The best-performing algorithm is represented by the following equations.

Sentinel-2 vegetation indices (IRECI and TRVI) derived from AGC:

$$AGC = 13.99 + 104.741 \times IRECI + 3.025 \times TRVI$$

Sentinel-2 vegetation indices (TRVI and DVI) derived from AGC:

$$AGC = -33.385 + 27.576 \times TRVI + 201.012 \times DVI$$

For the identification of mangrove carbon in South Lembar Village, the equation using the Sentinel-2 vegetation indices IRECI and TRVI was applied. The model developed from this combination, as presented in Suardana et al. (2023), demonstrated high accuracy in predicting AGC. The correlation between predicted and observed AGC values from the IRECI and TRVI model was 0.95, indicating a strong agreement.

The mangrove ecosystem in Lembar Village, in its current condition, is projected to become a promising destination for nature-based tourism, particularly trekking activities. Based on the AGC model using the IRECI and TRVI indices—with a correlation coefficient of 0.95—the mangrove density is classified as medium to high.

3.4 Assessment of tourism trekking trails: Landscape potential

The assessment was conducted using scoring and weighting methods, where scoring refers to a data processing procedure carried out after the reclassification process (Muhamad, 2017). This process involved assigning values to each parameter and criterion for evaluating the suitability of nature tourism trekking trails, followed by calculations that accounted for the most significant determining factors (Fandeli & Muhamad, 2007). Abiotic variables were used as key components in determining whether an area is suitable for nature-based trekking trails in mangrove regions. The process included documenting correction factors related to landscape potential, based on the Bureau of Land Management (BLM) Index. The

Table 1 . Assessment of landscape potential index for mangrove trekking trail tourism areas

No.	Criteria	Scoring
1	Low rolling hills; foothills or valley floors without distinctive landscape features	1
	Steep ravines/slopes, volcanic cones, or attractive erosion patterns; varied land sizes and shapes or dominant detailed features	
	High vertical relief with prominent peaks; tower-like peaks; giant rock outcrops or stunning surface variations; easily eroded formations or highly prominent dominant features	
	Several mangrove species but only 1-2 dominant types	
2	Little or no variation in mangrove vegetation	2
	Subtle color contrasts, generally appearing lifeless in mangrove areas	3
	Various color types present, with contrasts between soil, rock, and vegetation, but not dominating the scenery	5
3	Diverse color combinations or beautiful contrasts of soil, rock, vegetation, water (especially mangroves), and other elements	4
	Nearby views have little/no influence on scenic quality	3
4	Nearby views moderately influence scenic quality	5
	Nearby views significantly influence scenic quality	4
5	Has an interesting background but similar to general conditions in the area	3
	A distinctive/different area from other objects, creating unique impressions despite similarities to certain regions	2
6	Modifications add variety but strongly contrast with nature, creating disharmony	2
	Modifications add little or no landscape diversity	1
	Development of facilities (electrical installations, water channels, houses) provide modifications that enhance visual diversity	3
Total Landscape Potential Index		**38**

assessment relied on a set of criteria points for each landscape element, including landform, vegetation, color, scenery, scarcity, and structural modifications, as outlined in Table 1.

The obtained score of 38 across six criteria, with an average of 6.3, indicates that overall improvement is needed to enhance the harmony and environmental support of the mangrove area. This landscape assessment falls under the subcategory of landscape quality evaluation. Landscape quality is assessed both as part of strategic planning and in the context of specific developments that may impact the area.

Criteria showing excellent harmony were observed in criteria numbers 2 and 5, where the mangrove area in Lembar Village exhibits a variety of colors from soil, rock, and vegetation—though these are not dominant visual elements. The criterion related to nearby views, which moderately influence scenic quality, is particularly important in attracting tourists and enhancing the visual appeal of the trekking trail.

4. CONCLUSION

Mangrove trees are among the most effective plant species for carbon absorption. They capture atmospheric CO_2 through photosynthesis and store it in their trunks, leaves, and roots as biomass. The study findings show that the identification of mangrove species in zones near the Lembar Village ecosystem reflects a succession process and represents the ecosystem's response to external environmental factors. This adaptation underscores the ecological function and resilience of mangrove species in coastal areas. The research also indicates that maximizing carbon sequestration potential requires a focus on increasing above-ground biomass rather than soil carbon, as soil organic matter is relatively limited and less stable over time. Furthermore, the assessment of tourism trekking trails in terms of landscape potential and quality is considered favorable. This supports strategic planning for sustainable tourism development, where landscape characteristics play a critical role in enhancing the appeal of nature-based tourism.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Badan Riset dan Inovasi Nasional (BRIN) – the National Research and Innovation Agency of Indonesia – for funding support under the relevant research grant scheme.

CONFLICT OF INTERESTS

Our articles are free from disputes and conflicts of interest.

REFERENCES

Ario, R., Subardjo, P., & Handoyo, G. (2016). Analisis kerusakan mangrove di pusat restorasi dan pembelajaran mangrove (PRPM), Kota Pekalongan. *Jurnal Kelautan Tropis*, *18*(2).

Arief, A. (1994). *Hutan, hakekat dan pengaruhnya terhadap lingkungan*. Yayasan Obor Indonesia.

Farista, B. & Virgota, A. (2021). Serapan karbon hutan mangrove di Bagek Kembar Kecamatan Sekotong Kabupaten Lombok Barat. *Bioscientist: Jurnal Ilmiah Biologi*, *9*(1), 170—178.

Fandeli, C. & Muhamad, M. (2007). *Prinsip-prinsip dasar mengkonservasi lanskap*. Gadjah Mada University Press.

Fitria, A. (2021). Ekosistem mangrove dan mitigasi pemanasan global. *Jurnal Ekologi, Masyarakat, dan Sains*, *2*(1), 29—34.

Mulyadi, E., Hendriyanto, O., & Fitriani, N. (2010). Konservasi hutan mangrove sebagai ekowisata. *Jurnal Ilmiah Teknik Lingkungan*, *2*(1), 11—18.

Muhamad, M. (2017). Tapak ekologi kepariwisataan alam pada zona pemanfaatan di Taman Nasional Gunung Merapi (TNGM) (Konsep pengembangan kepariwisataan alam tematik tapak kawasan Kalikuning-Kaliadem sebagai kawasan budaya vulkanik). *Kawistara: Jurnal Ilmiah, Sosial, dan Humaniora*, *7*(3).

Muzani, A. P., Meylani, E. S., Andika, R., & Nurfadilah, R. (2020). Potensi Taman Mangrove Pulau Pramuka sebagai destinasi edutourism. *Jurnal Hutan Tropis*, *8*(3). https://doi.org/10.22146/kawistara.18828

Rahman, F. A. (2022). *Ekologi mangrove pulau lombok*. UIN Mataram Press.

Suardana, A. A. M. A. P., Anggraini, N., Nandika, M. R., Aziz, K., As-Syakur, A. R., Ulfa, A., Wijaya, A. D., Prasetio, W., Winarso, G., & Dimyati, R. D. (2023). Estimation and mapping above-ground mangrove carbon stock using sentinel-2 data derived vegetation indices in Benoa Bay of Bali Province, Indonesia. *Forest and Society*, *7*(1), 116—134. https://doi.org/10.24259/fs.v7i1.22062