

## MULTITEMPORAL ANALYSIS OF MANGROVE LAND COVER CHANGES IN CILACAP COASTAL AREA USING RANDOM FOREST ALGORITHM (2019–2024)

Abdul Halim Siregar<sup>1</sup>, Dodik Ridho Nurrochmat<sup>2\*</sup>, Yudi Setiawan<sup>3</sup>.

<sup>1</sup> Program Studi Ilmu Pengelolaan Sumberdaya Alam dan Lingkungan, Institut Pertanian Bogor

<sup>2</sup> Departemen Manajemen Hutan, Fakultas Kehutanan dan Lingkungan, Institut Pertanian Bogor

<sup>3</sup> Departemen Konservasi Sumberdaya Hutan dan Ekowisata, Fakultas Kehutanan dan Lingkungan, Institut Pertanian Bogor

E-mail: [msihalim@apps.ipb.ac.id](mailto:msihalim@apps.ipb.ac.id), [dnurrochmat@apps.ipb.ac.id](mailto:dnurrochmat@apps.ipb.ac.id), [setiawan.yudi@apps.ipb.ac.id](mailto:setiawan.yudi@apps.ipb.ac.id).

Received: 11/03/2026 | Revised: 20/03/2026 | Accepted: 02/04/2026 | Published: 13/04/2026

### Abstract

The mangrove area of 6,286.80 hectares, managed by KPH Banyumas Barat on the coast of Cilacap Regency, faces various anthropogenic pressures, including land conversion to fishponds, residential expansion, and port or fishing infrastructure. However, comprehensive studies on the temporal dynamics of mangrove land cover change in this area remain very limited, even though this information is essential for formulating effective conservation and management strategies. This study aims to examine the multitemporal dynamics of mangrove land cover change (2019–2024) in KPH Banyumas Barat, Cilacap Regency, using a machine learning approach that combines Sentinel-2 imagery, multispectral vegetation indices, and Random Forest classification on the Google Earth Engine platform. The results show a decline in mangrove cover of 533.6 ha over the 2019–2024 period. Two phases of change were identified: during 2019–2022, mangrove area showed an increasing trend of 46.4 ha, while during 2022–2024, mangrove area decreased by 580.1 ha due to both natural and anthropogenic processes, which may weaken the ecological functions of the area, reduce coastal protection against abrasion, and threaten the livelihoods of coastal fishing communities whose income depends directly on the productivity of the mangrove ecosystem.

**Keywords:** KPH West Banyumas. land use change, mangrove, Random Forest.

### INTRODUCTION

Land cover and land cover are important parameters in various fields such as environmental assessment, climate change, and sustainable development (Ganjirad and Hossein 2024). Changes in land cover, such as land use conversion, can have significant impacts on the ecological balance, hydrological cycle, and biodiversity of an area, triggered by interactions between natural and anthropogenic processes (Mishra et al. 2025). The link between land cover changes and various aspects such as climate, ecosystem processes, biogeochemical cycles, biodiversity, and human activities significantly contribute to ecosystem vulnerability, which has a non-negligible impact (Agaton et al. 2016).

Mangrove forests are globally recognized as carbon-rich tropical ecosystems that provide a range of critical economic and ecological services to surrounding coastal populations (Goldberg et al. 2020). The contribution of mangroves is crucial given their ability to absorb CO<sub>2</sub> from the atmosphere and store it in biomass and sediments for periods of hundreds to thousands of years (Howard et al. 2017). However, in these regions, mangrove ecosystems face increasing threats, primarily from anthropogenic interventions, including land cover change and land cover changes driven by agriculture, aquaculture, infrastructure expansion, and socio-economic pressures (Becker et al. 2025). Mangrove forests have been severely impacted by degradation and deforestation, with 20%–35% of global mangrove forest area lost in the past 50 years (Goldberg et al. 2020; Polidoro et al. 2010). Mangrove forest losses in the 20th century were largely due to forest clearing and exploitation for timber and raw material production, as well as rapid coastal population growth and urban expansion (Goldberg et al. 2020).

The West Banyumas Forest Management Unit (FMU) on the coast of Cilacap Regency, Central Java, manages one of the largest mangrove areas on the island of Java, with a total area of 6,286.80 hectares spread across

# MULTITEMPORAL ANALYSIS OF MANGROVE LAND COVER CHANGES IN CILACAP COASTAL AREA USING RANDOM FOREST ALGORITHM (2019–2024)

Abdul Halim Siregar et al

seven sub-districts. This area holds a strategic position as a green belt protecting the Cilacap industrial area and supporting the livelihoods of coastal communities. Despite its high ecological and economic value, the area faces anthropogenic pressures in the form of land conversion to fishponds, residential expansion, and port infrastructure development, as well as natural threats such as coastal erosion and industrial waste pollution (Schaduw et al., 2024; Trégarot et al., 2021). However, comprehensive studies on the temporal dynamics of mangrove land cover change in this area are still very limited, even though this information is crucial for formulating effective conservation and management strategies.

Advances in remote monitoring enable rapid mapping of mangrove changes using diverse observational data coverage, complex classifications, and efficient and cost-effective methods suitable for physically difficult-to-reach areas (Baloloy et al. 2020). Remote sensing technology has developed rapidly and proven effective for monitoring land cover change at wide spatial scales with high temporal resolution (Zhang et al. 2021).

Geographic Information Systems (GIS) can be used for vegetation monitoring, capable of visualizing and analyzing spatial data through satellite imagery. Various vegetation indices and multispectral image analysis are used to assess changes in mangrove cover (Puspitasari et al. 2024). The development of cloud computing platforms such as Google Earth Engine (GEE) has revolutionized remote sensing data processing by providing access to a vast catalog of satellite imagery and rapid processing capabilities without the need for expensive local computing infrastructure. The integration of GEE with machine learning algorithms such as Random Forest (RF) has shown very promising results in land cover classification with high accuracy (Jhonnerie et al. 2014; Purwanto et al. 2023).

The advantages of RF include the ability to handle high-dimensional data, are not susceptible to overfitting, and are able to identify the most important variables without assuming certain data distributions (Darmawan and Trio 2024). Therefore, this study was conducted with the aim of analyzing changes in mangrove land cover in the West Banyumas FMU, Cilacap Regency in 2019-2024 with the integration of Geographic Information Systems and Machine Learning using a combination of Sentinel-2 imagery, multi-spectral vegetation indices, and Random Forest classification based on the Google Earth Engine platform. The results of this study are expected to support the development of mangrove conservation strategies to achieve Indonesia's NDC targets, and the sustainable management of blue carbon ecosystems in the West Banyumas FMU.

## METHOD

### A. Time and Place

The research was conducted in January - May 2025 in the mangrove area of the West Banyumas Forest Management Unit, Cilacap Regency, Central Java Province, which is geographically located at coordinates 7°40'–7°50' South Latitude and 108°50'–109°00' East Longitude (Figure 1). This area covers seven sub-districts with a total mangrove area of 6,286.80 hectares, including Bantarsari, Karangpucung, Central Cilacap, Kampunglaut, Kawunganten, Jeruklegi, and North Cilacap.

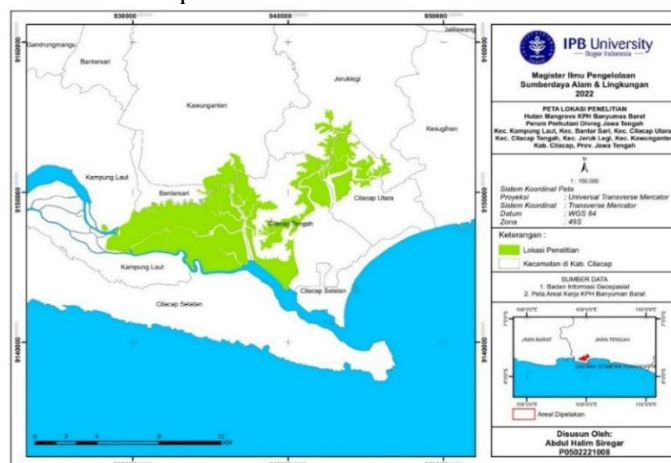


Figure 1 Map of research location

### B. Tools and materials

The tools used consisted of a computer with Google Earth Engine (GEE) software, ArcGIS 10.4, SPSS, and Microsoft Excel, as well as field equipment, namely the Global Positioning System (GPS). The data used to monitor the mangrove area consisted of Sentinel-2 MSI satellite imagery obtained from Google Earth Engine (GEE) cloud

computing storage. Sentinel-2 imagery is designed to monitor the Earth's surface and is equipped with 13 multispectral bands with spatial resolutions ranging from 10 to 60 meters (Pustitasari et al. 2022). In addition, administrative data for Cilacap Regency from the Geospatial Information Agency (BIG) was also used. As supporting data, this study utilized multi-temporal land cover maps from the Ministry of Environment and Forestry (KLHK) for 2019-2024 to assist in interpreting the direction of vegetation change.

### **C. Work procedures**

Analysis of changes in mangrove forest area was conducted using the Google Earth Engine (GEE) platform, a cloud-based computing platform that enables efficient processing of large-scale geospatial data. Classification and monitoring of mangrove cover changes were performed using the Random Forest (RF) supervised classification approach, known to be effective in detecting land cover changes with a high degree of accuracy (Hakim et al. 2022). Image preprocessing was carried out by creating a cloud-free composite by applying a cloud-free mask function to the Sentinel-2A image collection. Next, spectral transformation was performed to generate various vegetation indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), Modified Normalized Difference Water Index (MNDWI), Simple Ratio (SR), Band Ratio (54 and 35), and Green Chlorophyll Vegetation Index (GCVI), which were used as additional input in the classification process (Purwanto et al. 2023).

The Random Forest Classification algorithm works by building a number of decision trees which are then combined to obtain more accurate prediction results through a majority voting method (Purwanto et al. 2023). The optimal configuration used is 100 trees ( $n_{tree} = 100$ ) with 5 predictor variables ( $m_{try} = 5$ ), in accordance with the recommendations of Jhonnerie et al. (2014). Training samples for classification were collected through visual interpretation using high-resolution imagery and field verification.

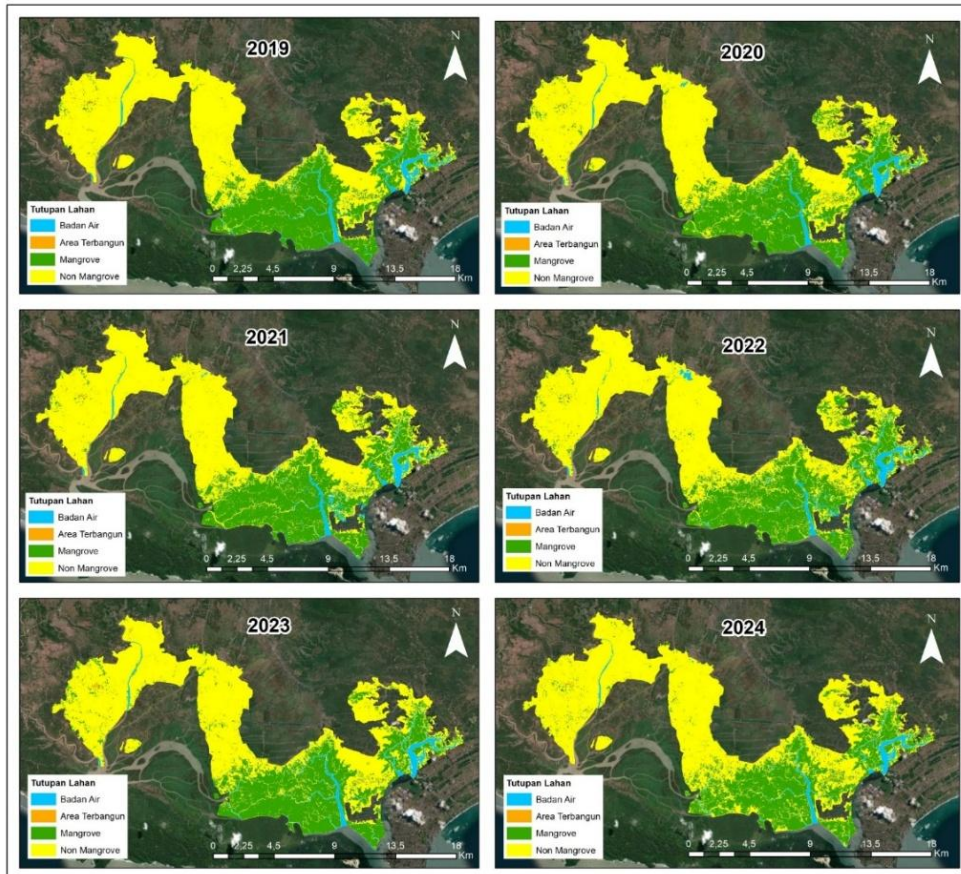
## **RESULTS AND DISCUSSION**

Mangrove ecosystems possess diverse potential, so the loss of mangrove cover during the 2019–2024 period will have significant physical, economic, and ecological impacts. As swamp forests, mangroves have a remarkable ability to absorb and store more carbon than many other plant species, making them vital in mitigating carbon emissions. However, land-use changes have reduced their role as effective CO<sub>2</sub> sinks (Puspitasari et al. 2024). Furthermore, this can weaken coastal protection, potentially accelerating erosion and threatening the safety of coastal infrastructure.

Changes in Mangrove land cover in the West Banyumas FMU on the coast of Cilacap Regency, Central Java throughout 2019-2024 experienced a decrease in area of 533.6 ha. In 2019-2022 the area of mangroves showed a relatively stable trend with a tendency to experience a slight increase, namely from 5,249.6 ha in 2019 to 5,296.1 ha in 2022. An increase of 46.4 ha over three years illustrates the condition of the mangrove ecosystem during that period was in a well-maintained condition which could occur due to the effectiveness of the rehabilitation and protection program for mangrove areas such as the implementation of the National Mangrove Action Plan (RAN Mangrove) which is part of Indonesia's commitment to reducing greenhouse gas emissions through the forestry sector and land use. In addition, the Ministry of Environment and Forestry (KLHK) through the Ecosystem Recovery and Forest and Land Rehabilitation (RHL) program consistently allocates mangrove planting targets in coastal areas, including in Central Java. In addition, the West Banyumas Forest Management Unit (KPH) as a forest management unit carries out the function of protecting mangrove areas which is strengthened by the Social Forestry program through the Community Forest (HKm) scheme which works in collaboration with coastal community groups., encouraging the active involvement of local communities in maintaining and rehabilitating mangrove areas, so that pressure on the ecosystem can be minimized. The spatial distribution pattern of mangrove areas is in line with research conducted by Rachmansyah et al. (2023) which states that the Segara Anakan mangrove ecosystem still has relatively well-maintained cover despite facing increasing anthropogenic pressure. The results of the analysis of changes in mangrove land cover are presented in Table 1 and Figure 2.

**MULTITEMPORAL ANALYSIS OF MANGROVE LAND COVER CHANGES IN CILACAP COASTAL AREA USING RANDOM FOREST ALGORITHM (2019–2024)**

Abdul Halim Siregar et al



**Figure 2 Changes in mangrove land cover 2019-2024**

**Table 1 Changes in mangrove land cover 2019-2024**

Year	Mangrove Area (ha)	Change (ha)	Rate (%/year)
2019	5,249.6	—	—
2020	5272.4	+22.8	+0.43
2021	5241.8	-30.6	-0.58
2022	5296.1	+54.3	+1.04
2023	5257.5	-38.6	-0.73
2024	4716	-541.5	-10.30

Meanwhile, between 2022 and 2024, mangrove area decreased by 580.1 ha. This significant decrease is not only caused by natural processes but also by anthropogenic processes. Globally, most direct anthropogenic losses are concentrated in six countries: Indonesia, Myanmar, Malaysia, the Philippines, Thailand, and Vietnam, with 82% of the losses being caused by human activities (Goldberg et al. 2020). The increase in built-up land area, which increased from 24.8 ha in 2019 to 68.4 ha in 2024, indicates land conversion to residential areas or coastal infrastructure development (Table 2). Population growth and economic development have increased the need for land. The lack of arable land is one of the most important factors driving land conversion to other uses, particularly agricultural land (Aida et al. 2023). From an economic perspective, mangrove degradation directly impacts the ecosystem services that support local economies. The Segara Anakan mangrove area is the main fishery resource for communities in seven sub-districts, because the life cycle of fish, shrimp, and mangrove crabs with high economic value is highly dependent on the existence of the mangrove ecosystem, also the majority of the population in this

# MULTITEMPORAL ANALYSIS OF MANGROVE LAND COVER CHANGES IN CILACAP COASTAL AREA USING RANDOM FOREST ALGORITHM (2019–2024)

Abdul Halim Siregar et al

area earns a living as fishermen who are structurally highly dependent on the sustainability of the mangrove ecosystem as a buffer for aquatic productivity (Rachmansyah et al. 2023).

Furthermore, the increase in non-mangrove cover in 2024 to 10,876 ha also illustrates the loss of some mangrove areas due to physical disturbances and degradation. Mangrove area conversion can be caused by social, ecological, and political conditions ranging from climate change and natural disturbances to pollution and anthropogenic exploitation of mangrove resources (Elfayetti et al. 2024). Ecological factors include climate change and natural disasters such as cyclones and tsunamis. Anthropogenic factors are usually caused by deforestation. Changes or losses in mangrove areas are also caused by forest clearing and exploitation for timber and raw material production, as well as rapid coastal population growth and urban expansion. Economic and political pressures on aquaculture development have also led to the massive conversion of mangrove forests into shrimp and rice ponds to capitalize on the growing global demand for aquaculture (Friess et al. 2016). Fisheries and agriculture have been the main causes of mangrove deforestation, with approximately 47% of the world's mangrove cover being lost due to these activities (Elfayetti et al. 2020; Latif and Hanum 2014).

**Table 2 Changes in the area of each land cover**

	2019	2020	2021	2022	2023	2024
Water Body	666.5	668.4	666.1	709.5	650.4	555.3
Mangrove	5,249.6	5,272.4	5,241.8	5,296.1	5,257.5	4,716
Built-up Land	24.8	33.4	42.3	48.7	54.1	68.4
Non-Mangrove	10,250	10,236.2	10,265.6	10,161.5	10,254	10,876

Efforts to restore mangrove cover in the West Banyumas Forest Management Unit (KPH) cannot be separated from strategies to improve community welfare, because improving ecosystem sustainability and the sustainability of community socio-economic life are interrelated elements in sustainable coastal area management. Therefore, an integrated approach that synergistically integrates ecological, economic, and social dimensions is needed as the main foundation in realizing the sustainability of the mangrove ecosystem (Elfayetti et al. 2024). Mangrove rehabilitation programs need to be implemented in a planned manner and based on accurate spatial data, including identification of critical zones, selection of mangrove species appropriate to local characteristics and hydrological conditions, and regular growth monitoring. The success of mangrove rehabilitation is determined not only by the number of seedlings planted, but also by the survival rate of the plants and the ability of the ecosystem to restore its ecological functions, such as coastal protection from abrasion, carbon sequestration, and providing habitat for marine biota (Kusmaningtyas et al. 2021).

In addition, from an economic perspective, coastal communities can obtain direct benefits through the development of mangrove ecotourism, silvofishery systems, and management of non-timber forest products (NTFPs), so that mangroves are seen as productive assets worthy of protection, not just resources to be exploited (Salmah et al. 2021). Furthermore, from a social and institutional perspective, this can be done by strengthening community groups that care about mangroves, implementing community-based monitoring, and synergizing between the local government, the West Banyumas Forest Management Unit (KPH), NGOs, and the private sector as a foundation for participatory and accountable governance.

## CONCLUSION

Analysis of multitemporal mangrove land cover changes with a Random Forest classification approach that integrates Sentinel-2 imagery, multispectral vegetation indices, using the Google Earth Engine platform is able to provide a comprehensive picture of the dynamics of temporal changes in mangrove land cover in the coastal area of the West Banyumas FMU, Cilacap Regency, and produces data that can be used as a basis for conservation planning and sustainable management of mangrove areas.

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**MULTITEMPORAL ANALYSIS OF MANGROVE LAND COVER CHANGES IN CILACAP COASTAL AREA USING RANDOM FOREST ALGORITHM (2019–2024)**

Abdul Halim Siregar et al

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