

Coastal Protection Service as an Indirect Benefit of Mangrove Forest in the Coastal Area of Simboro District, Mamuju Regency

Nurhalisah^{1*}, Haryanto², Binayanti³, Israwahyudi⁴, Ilham⁵

Universitas Muhammadiyah Mamuju

Corresponding Author: Nurhalisah nurhalisahsyamsul2004@gmail.com

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ABSTRACT

Mangrove ecosystems play an important role as a natural protector of coastal areas against abrasion and wave threats, and generate indirect economic benefits in the form of coastal protection services. This study aimed to analyze the condition of the mangrove ecosystem and to estimate the economic value of the coastal protection services it generates in the coastal area of Simboro District, Mamuju Regency. The research was conducted from May to June 2026 using a quantitative descriptive approach. The area and distribution of mangroves were estimated through delineation of Sentinel-2 satellite imagery using QGIS software and verified through field surveys, while the economic value of coastal protection services was calculated using the Replacement Cost Method (RCM) based on the construction cost of a breakwater as substitute infrastructure. The results showed that the mangrove ecosystem in Simboro District has a cover area of 64.06 ha spread along 15,460 meters of coastline. Based on a unit construction cost of IDR 14,043,994.61 per meter, the estimated economic value of coastal protection services was IDR 217,120,156,671, or approximately IDR 217.12 billion. This value indicates that the presence of mangroves provides a substantial economic contribution through savings in the construction cost of artificial coastal protection infrastructure. This study recommends that mangrove conservation and rehabilitation be prioritized in the coastal management of Simboro District

INTRODUCTION

The mangrove ecosystem is one of the coastal ecosystems that has an important role in maintaining environmental balance and supporting the sustainability of coastal areas. Indonesia has the largest mangrove area in the world that functions as a habitat for various biota, carbon sinks, and natural protectors of coastal areas. In addition to providing direct benefits in the form of fishery products and other biological resources, mangroves also produce various indirect benefits of high ecological and economic value for coastal communities. One of the most important indirect benefits is coastal protection services from the threat of abrasion, waves, and tidal floods (Kurniawansyah et al., 2023; Rahmawati et al., 2022).

Coastal protection services are part of the regulating ecosystem services produced by mangrove forests. Mangrove roots, stems, and crown structures are able to dampen ocean wave energy, slow down currents, and hold sediment so that it can reduce the level of coastal abrasion. The existence of mangroves functions as a natural barrier that protects coastal areas from physical damage due to marine dynamics. Coastal areas that have good mangrove cover tend to have a lower rate of coastal damage than areas that experience mangrove degradation (Saputra et al., 2022; Fadilah et al., 2023).

In recent decades, Indonesia's coastal regions have faced various environmental pressures due to climate change, increased development activities, and the conversion of coastal land. These conditions have led to a reduction in the area and quality of mangrove ecosystems in various regions, thereby reducing the ability of ecosystems to protect coastlines and increasing the risk of abrasion. The loss of mangrove vegetation can accelerate the rate of abrasion and increase the vulnerability of coastal areas to the threat of sea waves (Octavian et al., 2022). Therefore, the existence of mangroves is an important component in efforts to mitigate coastal damage in a sustainable manner.

Simboro District, Mamuju Regency is one of the coastal areas that has a mangrove ecosystem that functions as a natural protector of the coastline. This area is directly adjacent to the Makassar Strait so that it is influenced by wave activity and coastal dynamics that are quite high. Environmental pressure and community activities have the potential to affect the condition of mangroves and their effectiveness in carrying out coastal protection functions, so a study is needed that can explain the extent of the role of mangroves in protecting coastal areas in this area.

In addition to having an ecological function, coastal protection services produced by mangroves also have great economic value because they are able to reduce the costs that must be incurred by the government or community to build coastal protection infrastructure such as breakwater or abrasion-resistant embankments. Menéndez et al. (2020) show that mangroves are able to provide protection against the risk of flooding and coastal damage with very significant economic value on a global scale. However, research that examines the value of indirect benefits of mangroves as coastal protection services quantitatively is still relatively limited, especially at the local level in Mamuju Regency (Efriyeldi et al., 2024; Pradana & Susilo, 2024).

Based on this description, this study aims to analyze the condition of the mangrove ecosystem and estimate the economic value of the coastal protection services it produces in the coastal area of Simboro District, Mamuju Regency through the Replacement Cost Method approach, which is based on the cost of building coastal protection buildings that must be incurred if the mangrove protection function is not available. The results of the study are expected to be a scientific basis in supporting sustainable mangrove management and conservation policies in the coastal area of Simboro District.

METHODS

Research Time and Location

This research was carried out for ± 2 (two) months, starting from May to June 2026, including the preparation stage, data collection, data processing, and report preparation. The research was carried out in the mangrove ecosystem area of Simboro District, Mamuju Regency, West Sulawesi Province, which is a coastal area that is directly adjacent to the Makassar Strait and has a stretch of mangroves along its coastline.

Tools and Materials

The tools and materials used in this study include digital cameras/smartphones for documentation of field conditions, GPS (Global Positioning System) for determining the coordinate points of mangrove area boundaries, stationery and observation sheets for recording field data, Google Earth Pro/QGIS software for delineation and estimation of mangrove cover area, Sentinel-2/Landsat satellite image data for mapping the distribution and area of mangroves, and Microsoft Excel for processing and calculating economic valuation data.

Data Types and Sources

The type of data used in this study consists of primary data and secondary data. Primary data was obtained directly through field observation, including the physical condition of coastlines in different mangrove zones (tight, moderate, and open/without mangroves) as well as verification of mangrove area boundaries using GPS. Secondary data includes Sentinel-2/Google Earth Pro satellite imagery for delineation and estimation of mangrove cover area, as well as breakwater/embankment work unit price data from the Mamuju Regency Public Works Office or Work Unit Price Analysis (AHSP).

Population and Sample

The population in this study is all mangrove ecosystem areas in the coastal area of Simboro District. The research sample was determined using the purposive sampling technique, which is a sampling technique based on certain considerations that are in accordance with the research objectives (Sugiyono, 2022), with the following criteria: (1) areas that have mangrove cover, (2) areas that experience abrasion or wave pressure, and (3) locations that represent different mangrove conditions (close, medium, rare).

Analysis of Abrasion Prevention Services Valuation (Replacement Cost Method)

The economic valuation analysis was carried out using the replacement cost method. This approach calculates the value of the indirect benefits of

mangroves as abrasion prevention based on the costs that must be incurred if the coastal protection function that has been provided by mangroves must be replaced with artificial building structures in the form of breakwater or abrasion-resistant embankments (Hidayah et al., 2020; Marinda et al., 2021). The basis for this method is that if mangroves do not exist, then the government or community must build physical infrastructure to protect the coastline from abrasion, so that the cost of infrastructure development reflects the economic value of the services that mangroves have been provided for free as natural capital.

The mangrove cover area (L, in Ha) was estimated through the delineation of Sentinel-2 satellite imagery using QGIS software, which was then verified with GPS coordinate data from field surveys. From the results of the deliniation, the length of the coastline that is actually protected by the mangrove belt (P, in meters) was also obtained. The economic value of abrasion containment services (NPA) was calculated by multiplying the length of the mangrove-protected coastline (P) by the cost of the breakwater construction unit (C) per meter, using an equation (Hidayah et al., 2020):

$$NPA = P \times C$$

Description: NPA = economic value of abrasion barrier services (Rupiah); P = length of mangrove-protected coastline (meters); C = unit cost of breakwater/embankment construction (Rp/meter). The C value is obtained from breakwater work unit price data sourced from the Mamuju Regency Public Works Office. To facilitate interpretation, the economic value of abrasion barrier services is also expressed in units per hectare of mangroves ($NPA/Ha = NPA/L$), with L being the total area of mangrove cover (Ha). The data was analyzed descriptively quantitatively with the help of QGIS and Microsoft Excel software.

RESULTS AND DISCUSSION

Mangrove Ecosystem Conditions

Based on the results of the interpretation of the Sentinel-2 image in 2026 and the process of delineation of mangrove cover, the area of the mangrove ecosystem in the coastal area of Simboro District, Mamuju Regency was obtained of 64.06 ha. The mapping results showed that the mangrove ecosystem was spread across several parts of the coastal area and was located in an area adjacent to the coastline (Figure 1). The existence of mangroves in the area shows that this ecosystem has an important position as a natural protective vegetation of the coast, because its trunk structure and root system help reduce the pressure of waves that reach the coastline and retain sediment in the coastal area.

The mangrove cover area of 64.06 ha cannot be used as the only indicator to determine the level of effectiveness of coastal protection, because the effectiveness of protection is also influenced by the condition and density of vegetation as well as the physical condition of the coastline. The mapping results show that the condition of mangrove vegetation cover is not uniform in all areas; areas with wider and integrated cover indicate closer vegetation conditions, while areas with more disconnected cover indicate relatively sparsely populated vegetation conditions, in addition to open parts of the coastline without

mangrove cover. In this study, quantitative tree density measurement data is not available, so the condition of mangrove density is described descriptively based on the results of mapping and distribution of vegetation cover.

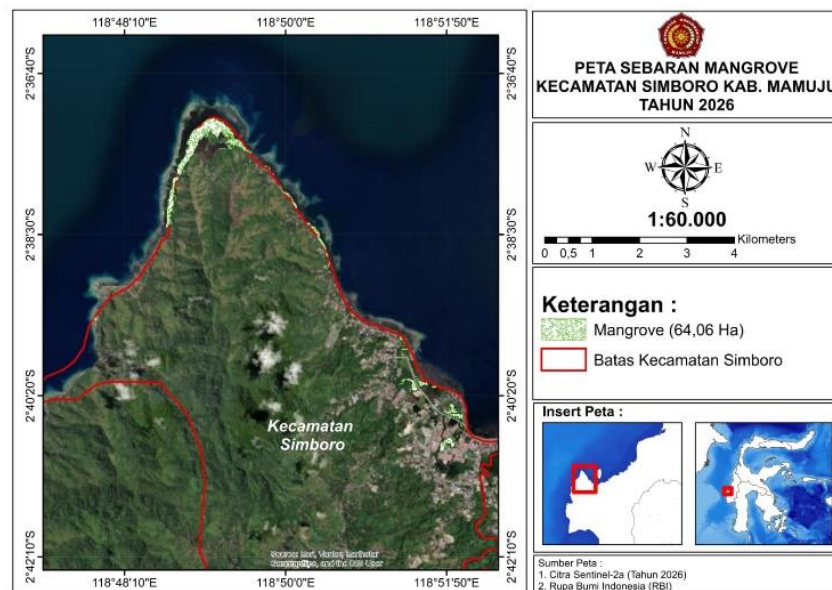


Figure 1. Mangrove Distribution Map of Simboro District, Mamuju Regency in 2026

Mangroves have an ecological function as a natural protector of coastal areas because their vegetation structure provides an obstacle to the movement of water and waves towards the coastline. Areas with more ecologically tight mangrove cover have greater protection potential than areas with less sparsely or open vegetation cover. This study has not obtained quantitative wave energy measurement data before and after passing through mangrove areas, so wave energy reduction is discussed as an ecological function of mangroves that support shoreline protection, in line with the findings of Pramudji et al. (2021) and Saputra et al. (2022) that the width of the belt and the density of mangroves play an important role in reducing wave energy in coastal areas.

Economic Value of Coastal Protection Services

The assessment of coastal protection services in this study was carried out using the Replacement Cost Method (RCM), which is by estimating the value of the indirect benefits of mangroves based on the costs that are theoretically needed if the natural protection function of mangroves must be replaced with artificial infrastructure in the form of breakwater. Based on data on the cost of construction of an 890-meter breakwater of IDR 12,499,155,200, a unit cost of breakwater construction of IDR 14,043,994.61 per meter was obtained. The unit cost is then used as a replacement cost in estimating the value of mangrove coastal protection services at the length of the coastline that is the object of the study.

Based on the results of measurements and mapping, the length of the coastline within the scope of mangrove protection is 15,460 meters. This length is multiplied by the cost of the breakwater construction unit to obtain an estimate of the economic value of coastal protection services, as presented in Table 1.

Table 1. Estimation of the Economic Value of Mangrove Forest Coastal Protection Services in Simboro District Using the Replacement Cost Method Approach

Components	Value	Remarks
Mold breakwater length	890 m	Length of infrastructure on cost data
Total reference breakwater cost	IDR 12,499,155,200	Overall cost 890 m
Breakwater cost per meter	IDR 14,043,994.61/m	Replacement unit cost
The length of the coastline is protected by mangroves	15,460 m	Measurement/mapping results
The value of coastal protection services	IDR217.120.156.671	Estimated replacement cost

The results of the analysis show that the economic value of coastal protection services by mangrove forests in Simboro District is Rp217,120,156,671, or around Rp217.12 billion. This value illustrates the amount of costs that must theoretically be incurred if the natural protection function of mangroves along the 15,460 meters of coastline is replaced by the construction of breakwaters, and is not the cost of breakwater construction that has actually been incurred. The value of Rp12,499,155,200 only serves as basic data to obtain the unit cost of breakwater per meter, so the two values have different functions in the analysis and cannot be treated as two equal economic values.

Discussion

The mangrove ecosystem in Simboro District has an area of 64.06 ha and is spread over coastal areas that are directly related to shoreline protection. This position allows mangroves to function as a natural barrier to wave pressure and help maintain shoreline stability, in line with Irwansah et al. (2023) who stated that the effectiveness of mangrove vegetation in mitigating coastal abrasion is greatly influenced by the condition and density of its cover. Therefore, the existence of mangroves is not enough to be assessed based only on the area area, but also needs to pay attention to the condition of the vegetation and its density level.

The economic value of coastal protection services of IDR 217.12 billion obtained in this study confirms that mangrove ecosystems have a large economic contribution through the protection function provided naturally. This value is in line with the findings of Marinda et al. (2021) and Fahrudin & Sadelie (2022) who show that the valuation of the indirect benefits of mangroves as coastal protection services produces significant economic value, and supports the findings of Menéndez et al. (2020) on a global scale that mangroves provide coastal flood protection benefits with great economic value. This value does not mean that the government has or will spend such a large amount of money for the construction

of breakwaters, but rather is an estimate of the theoretical replacement cost that describes the magnitude of the indirect benefits that mangroves have provided for free.

The large estimated value of coastal protection services shows that mangroves not only have ecological value, but also economic value related to the function of protecting coastlines. Damage or degradation of mangroves not only has the potential to reduce ecological function, but can economically increase the need for the cost of procurement of artificial coastal protection infrastructure (Angelina et al., 2024; Putri et al., 2025). Therefore, mangrove conservation and rehabilitation efforts need to be seen as part of a coastal area management strategy that at the same time provides ecological and economic benefits for the people of Simboro District.

CONCLUSION

The mangrove ecosystem in the coastal area of Simboro District, Mamuju Regency has a cover area of 64.06 ha spread across several parts of the coastal area and functions as a natural protector of the coastline through its ability to reduce wave pressure and reduce the risk of abrasion. Based on the Replacement Cost Method (RCM) approach, the economic value of coastal protection services produced by mangroves in the study area is estimated at Rp217,120,156,671 or around Rp217.12 billion, as an estimate of the replacement cost to protect 15,460 meters of coastline if the natural protection function of mangroves is replaced by breakwater. These results confirm that the conservation and rehabilitation of mangrove ecosystems needs to be a priority in the management of the coastal area of Simboro District, considering the great ecological and economic benefits it produces. Further research is suggested to complement the data on mangrove vegetation density in each zone quantitatively, so that the relationship between mangrove density, wave energy reduction, and the value of coastal protection services can be analyzed in more depth.

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