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A remote sensing-based analysis of mangrove vegetation density and damage levels for coastal ecosystem management

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ABSTRACT

Background: Mangrove ecosystems play an important role in the balance of the coastal environment but are degraded due to human activities and natural factors. This study aims to analyze the level of damage to mangrove vegetation in Paguyaman Pantai Subdistrict using a remote sensing approach. **Methods**: This research uses Landsat 8 and Sentinel 2 satellite imagery data, and the Normalized Difference Vegetation Index (NDVI) method to identify the level of vegetation density. **Findings:** The results showed that the total area of mangroves in this area is 436.16 Ha, with a classification of high density (248.56 Ha), medium (174.23 ha), and low (13.36 Ha). Damage to the mangrove ecosystem in Paguyaman Pantai District is not significant, because most areas are still dominated by high-density mangroves and overall, the mangrove ecosystem in this area remains in good condition and continues to play a role in maintaining the balance of coastal ecosystems. **Conclusion:** Field validation results show that mangroves in this area consist of six main species, namely Rhizophora stylosa, Sonneratia alba, Ceriops tagal, Ceriops decandra, Bruguiera cylindrica, and Bruguiera gymnorrhiza. **Novelty/Originality of this Study:** The novelty of this study lies in its application of remote sensing techniques to assess mangrove vegetation density, providing a comprehensive spatial analysis that supports conservation efforts and sustainable management.

KEYWORDS: beach protection; degradation; mangroves; NDVI; remote sensing.

1. Introduction

Mangroves are ecosystems that have an important role in maintaining the balance of the coastal environment, supporting biodiversity, and becoming a sustainable economic resource. Mangrove forests have unique characteristics, including their specific location, their unique ecological role, and their high economic potential (Romadoni et al., 2023; Setiawan, 2013; Wibowo, 2006). Wahyuni et al. (2014) said that mangrove ecosystem is one of the coastal natural resources that has an important role in terms of socio-cultural, economic, and ecological. From these three functions, the role of mangrove ecosystems is as follows; (1) physical functions to keep the coastline stable, accelerate land expansion, protect beaches and river cliffs, and process waste, (2) biological or ecological functions, namely nesting sites for large birds, natural habitats for many types of biota, nurseries,

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places to find food and lay eggs, and shelter for aquatic biota, and (3) economic functions include pond areas, salt, wood and beam making, and recreation. In addition, mangrove ecosystems have functions for the social life of the community and the environment (Setiawan, 2018).

According to Alwidakdo et al. (2014), mangrove forests are a natural resource that can be restored to its utilization, so it requires proper management to prevent damage and ensure its sustainability in the present and future. On the other hand, the biological nature of mangroves that grow in transitional areas between land and sea or called coastal areas, makes them very vulnerable to disturbance and damage. This disturbance can be caused by natural factors or human activities. Damage or loss of mangrove ecosystems can result in the loss of all its ecological and economic functions (Majid et al., 2016; Mughofar et al., 2018). Therefore, the existence and sustainability of mangrove forests greatly affect the balance of coastal areas and the lives of people living around them.

Wardhani (2011) suggests high population growth and rapid development activities in coastal areas with various designations (settlements, fisheries, ports, etc.), ecological pressure on coastal ecosystems, especially mangrove ecosystems are also increasing. This increased pressure certainly has an impact on damage to the mangrove ecosystem itself either directly, for example logging activities or land conversion, or indirectly, such as pollution by waste of various development activities. In addition, Martinuzzi et al, (2009) stated that human activities significantly reduce the area of mangrove ecosystems and change the original proportion of mangrove species, the quantity and quality conditions of mangrove ecosystems directly affect the lives of coastal communities (Akra & Hasnidar, 2022; Asirwan, 2017).

One of the coastal areas in Indonesia that has mangroves is Gorontalo province. Mangroves in Gorontalo Province are spread across several districts, namely Gorontalo Regency, Bone Bolango Regency, North Gorontalo Regency, Pohuwato Regency, and Boalemo Regency. There are five districts that have mangrove areas, one of which is Boalemo District. Based on data from the National Mangrove Map in 2021, the results of analysis on satellite imagery, mangrove forests in Boalemo Regency are found in five sub-districts as mangrove ecosystem areas with a total area of 1440.39 Ha. One of the areas in Boalemo Regency that has a mangrove area is Paguyaman Pantai Subdistrict. This sub-district is divided into eight villages, where the north borders Paguyaman sub-district and the east borders Bilato sub-district, the south borders Tomini Bay, and the west borders Paguyaman sub-district. Based on data released by Badan Pusat Statistik Kabupaten Boalemo (2014), Paguyaman Pantai sub-district is a sub-district with an area of 124.51 superscript base, k m, end base, squared and is mostly a coastal area. The average elevation of the area is 68 m above sea level. Based on a report from the 2021 National Mangrove Map obtained from BPDAS Bone Bolango, Paguyaman Pantai sub-district has a mangrove area of 437.43 Ha. Based on an initial survey conducted by the author, it is suspected that the mangrove area in this region is degraded. It is estimated that the form of mangrove area degradation that occurs includes; mangrove wood collection carried out by local residents who are utilized for firewood needs and the increase in waste, especially those made from plastic from local community activities, this will have a polluting impact on the mangrove area. Other activities that are thought to contribute to mangrove degradation in this area are the access roads that pass through the mangrove area to a special terminal port (jetty) for the transportation of excavation C mining products operated by companies in the area. The existence of some of these activities is thought to have a direct or indirect impact on mangrove degradation in the area.

Mangrove damage assessment is one of the efforts that can be done to determine the amount of damage. One way to do this is with a vegetation analysis approach. Mangrove vegetation analysis can be a way to understand the impact of exploitation on mangrove forests in Paguyaman Pantai District. There are many strategies in conducting vegetation analysis. In general, vegetation analysis is done with a manual approach, but along with the development of technology and information, vegetation analysis can be done with a more modern or digital approach. The application of remote sensing technology is one effective and efficient way to monitor the condition of mangrove ecosystems (Muhsoni, 2015). Lestari (2019) suggests that the use of remote sensing systems aims to be able to identify objects on the earth's surface through data analysis obtained by direct or indirect contact with objects or areas. Through this, efforts to obtain information and analyze changes in both damage and succession that occur are important through the help of remote sensing. Remote sensing uses satellite image data, the software used in this remote sensing is ArcGIS 10.4. The image data obtained is processed with the Normalized Difference Vegetation Index (NDVI) method to obtain the density level of a vegetation. Based on this description, research that examines the level of damage to mangrove vegetation in the Paguyaman Pantai District of Boalemo Regency by applying a remote sensing approach can be carried out.

2. Methods

This research will be planned in the mangrove area of Paguyaman Pantai District, Boalemo Regency. The selection of research locations at several observation station points, considered based on the condition of the ecosystem heterogeneity of the ecosystem and can represent the condition of the mangrove ecosystem in Paguyaman Pantai District. This research will be conducted from December 2024 to January 2025. This research activity was carried out by utilizing remote sensing technology in the form of high-resolution satellite imagery and field checks as validation of the actual condition of the coastal area. The expected results of the utilization of satellite imagery and field checks are the identification of changes in land cover and land area and changes in mangrove density in coastal areas. Satellite image data used includes recording in the past 1 year.

Data collection techniques, namely The initial stage of preparation was a literature study and collection of information from the community around the research area through surveys, by making preliminary observations in the field of mangrove plant population conditions to determine sampling locations. Descriptive data collection by field examination, remote sensing and geographic information systems (map interpretation), and literature study. Field inspection was carried out to study the actual conditions and take documentation. Image pre-processing is the first step in processing satellite images. The image pre-processing stage was carried out in ArcGis software version 10.4 with the Semi-Automatic Classification plugin which includes the process of atmospheric correction, cropping, and image resampling. The Dark Object Subtraction (DOS) method is used in the atmospheric correction process to reduce interference from the atmosphere and make it clearer to recognize objects when interpreted. The corrected pixels will be displayed in reflectance values. Image cropping is done to narrow down the study area and also reduce the file size of the image to speed up the processing process in the software. The last stage is image resampling with the Nearest Neighbor method. Image resampling is done to change the spatial resolution of the RED-Edge band from 20 meters to 10 meters (Pratama et al., 2019). The corrected Sentinel-2A image is then processed through the stages of Composite Image Preparation, Masking, and Spectral Transformation. RGB 432 (True Color) combination is the composite image used in this study. Processing was carried out in SNAP software version 5.0 using the red channel for channel 4 (band 4: 665 nm), the green channel in channel 3 (band 3: 560 nm) and the blue channel in channel 2 (band 2: 490 nm) which was used to identify mangrove forest objects (Pratama et al., 2019). Sampling in the field used stratified random and proportional sampling methods. In this study, plots with a size of 20m x 20m were used from 100 meters of plastic rope. The design of field observations with plot samples can be seen in Figure black dots in the center indicate mangrove density data collection points. Mangrove density measured in this study is the density of the crown. Mangrove canopy density was measured by taking vertical photographs using a camera with a Fish Eye lens at a point on each plot to see the entire plant part, especially trees and shrubs. This activity was carried out to identify mangroves present in the area and to ensure the presence of mangroves is accurate and in accordance with the data generated by the image.

Processing is carried out using ArcGIS 10.4 software by describing each classification that has been made previously. After obtaining the classification results, field data validation is carried out for further accuracy testing. Normalized Difference Vegetation Index (NDVI) is an image calculation used to determine the greenness of vegetation. NDVI can show parameters related to vegetation, including: green foliage biomass, green foliage area which is a predictable value for vegetation division. The index gives a number between -1 and 1 that represents the density of vegetation cover. In general, an index close to 1 means dense vegetation and less than zero represents water and clouds (Simarmata et al. 2021; Wibowo et al., 2015). Algorithms in remote sensing applications to measure the greenness of vegetation by utilizing near infrared and red waves (Putri, et al. 2018). The resulting index is a mathematical combination of the red band and the NIR (Near infrared radiation) band which is used as an indicator of the presence and condition of vegetation. Analysis material to classify mangrove conditions according to the medium, dense, and sparse categories (Dwiputra et al., 2020). Here is the NDVI equation.

$$\text{NDVI} = \frac{(NIR - Red)}{(NIR + Red)} \quad \text{(Eq. 1)}$$

The NDVI (Normalized Difference Vegetation Index) is a vegetation index used to measure the greenness or density of vegetation in a given area. It is calculated based on the difference between the reflectance values of the near-infrared (NIR) band and the red band. The NIR band reflects the high intensity of near-infrared light from healthy vegetation, while the red band captures the amount of light absorbed by chlorophyll in plants. By utilizing these two spectral bands, NDVI provides a spatial and temporal representation of vegetation conditions.

Making maps of mangrove distribution and damage is based on the results of accuracy tests that have been carried out. In Hidayanti (2023), said that to determine mangrove damage, it can be classified based on data from the Ministry of Environment and Forestry in 2021. Mangroves in Indonesia have 3 (three) classifications of mangrove condition categories according to the percentage of canopy cover, namely dense mangroves, moderate mangroves, and sparse mangroves. Referring to SNI 7717-2020, dense mangrove conditions are mangroves with canopy cover >70%, moderate mangroves with canopy cover 30-70%, and sparse mangroves with canopy cover <30%.

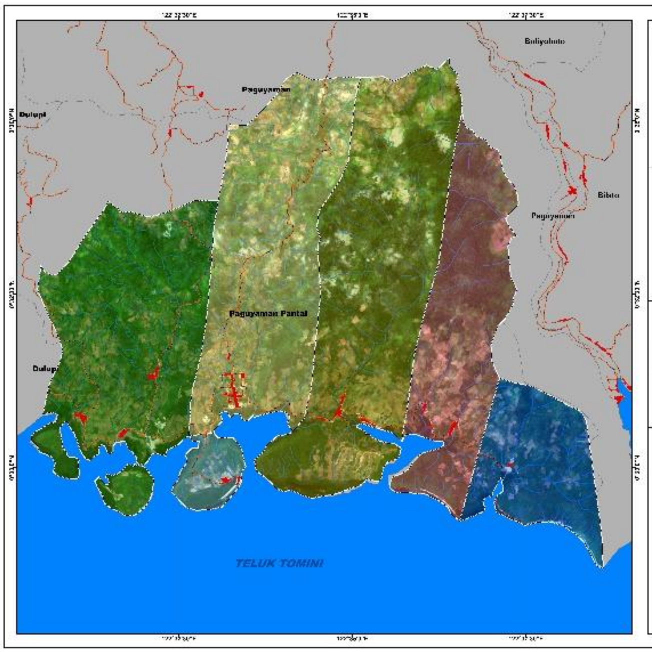

Fig. 1. Research location

3. Results and Discussion

The study covered mangrove areas in 6 villages in Paguyaman Pantai sub-district (Table 1). The results of observations made at the research site found 6 mangrove species. Mangrove ecosystems in Paguyaman Pantai Subdistrict, have a variety of species that grow naturally or through the results of planting in land rehabilitation programs. Various types of mangroves that are commonly found are 6 species of mangrove plants namely Rhizophora stylosa Blume, Ceriops tagal (Perr) C.B.Rob, Ceriops decandra, Bruguiera cylindrica, Bruguiera gymnorrhiza (L) Lamk, Sonneratia alba J.E. Smith. As for the six mangrove species based on the stature there are 5 species with tree stature namely; Rhizophora stylosa Blume, Ceriops decandra, Bruguiera cylindrica, Bruguiera gymnorrhiza (L) Lamk, Sonneratia alba J.E. Smith, and there is one species with seedling stature namely Ceriops tagal (Perr) C.B.Rob.

Table 1. Limitation of mangrove research location

No	Village name	Area (Km2)	Mangrove Area
1	Limbatihu	27.83	166.65
2	Bangga	1.93	69.23
3	Bubaa	26.03	41.49
4	Lito	18.94	92.91
5	Apitalawu	14.13	31.80
6	Olibu	8.48	34.06

Based on the results of data processing using ArcGIS 10.4 software with Landsat 8 satellite image data sources in 2024, it is found that mangroves are evenly distributed in all villages in the Paguyaman Pantai District. The area of the mangrove area is 436.16 ha. The mangrove distribution map is shown in Figure 2.

Fig. 2. Map of mangrove distribution in Paguyaman Pantai sub-district in 2024

Based on the image processing results obtained NDVI value range. This value can be used as the basis for mangrove density classification. There are three classes that make up the classification, namely rarely shown in red, medium shown in yellow, and dense shown in green. Below figure 4 displays a map of the distribution of mangrove density levels in Paguyaman Pantai sub-district in 2024.

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Fig. 3. Map of the distribution of mangrove density levels in Paguyaman Pantai sub-district in 2024

Based on the data from the classification of mangrove vegetation based on NDVI values, the area of each class of classification results can be found in Table 2. The distribution of mangroves obtained from satellite imagery needs to know the level of accuracy, for which validation is carried out using field data. Image accuracy is done on Landsat images in 2024. The number of sampling points as many as 6 villages which are coastal areas determined randomly through stratified random sampling in ArcGis 10.4 application. Sampling points are distributed in each class according to the level of mangrove density. Mangroves in Paguyaman Pantai sub-district are spread along the coastal area and based on the results of calculations obtained that in 2024 the area of mangrove forest distribution in Paguyaman Pantai sub-district is 436.16 ha. The condition of mangroves during observation is quite varied (Prima, 2018; Purwanto, 2015). This occurs due to the factor of tides and receding seawater which is one of the physical factors that occur in mangrove ecosystems. Mangroves that are submerged in tides generally have roots that can support their adaptation. According to Eddy et al. (2019) that there are four main factors that determine the distribution of mangrove forest plants, namely (1) the frequency of tidal currents, (2) soil salinity, (3) groundwater, and (4) water temperature. Soil salinity is strongly influenced by the height and length of tidal inundation. Mangrove vegetation consists of various plant species that are unique because they are able to grow despite exposure to waves and salinity of seawater in coastal environments. Furthermore, DasGupta & Shaw (2013) suggested that mangrove plants have morphological and physiological adaptability in the face of environmental and natural pressures in tidal habitats (Poedjirahajoe, 2007). Mangrove plants are able to develop unique adaptations, including adaptation to environments with low oxygen levels and high salinity; adaptation in supporting the life of other plants; adaptation to tissue loss; adaptation to nutrient uptake; and adaptation in maintaining propagule survival (Eddy et al., 2017).

Table 2. Classification of mangrove vegetation

Village Name	Density Class (Ha)			
	Low Density (<30%)	Medium Density (30-70%)	High Density (>70%)	Grand Total (Ha)/Percentage
Apitalawu	1.07	8.91	21.81	31.80
Bangga	1.12	34.33	33.78	69.23
Bubaa	1.24	13.85	26.39	41.49
Limbatihu	4.96	71.74	89.94	166.65
Lito	3.18	36.35	53.36	92.91
Olibu	1.76	9.03	23.25	34.06
Grand Total (Ha)	13.36	174.23	248.56	436.16
Persentase	3.06%	39.95%	56.99%	100%

Ridho (2016) suggests that mangroves develop specialized roots such as pneumatophores (breath roots) and lenticels on the stem or roots, which allow them to absorb oxygen directly from the air. In addition, mangroves are also able to adapt to high salinity conditions through various mechanisms, such as salt excretion through special glands on their leaves, salt filtration by the roots, and salt storage in old leaves which then fall to reduce salt levels in the body. In addition to surviving in extreme environments, mangroves also support other plant life by creating stable habitats and providing a source of nutrients through leaf drop and complex root systems. Mangroves also have the ability to quickly regenerate tissue damaged by abrasion, ocean waves or storms. To ensure optimal growth in nutrient-poor environments, mangroves develop symbiotic relationships with microorganisms in their roots to enhance nitrogen and phosphorus uptake. Mangroves also have a unique strategy in maintaining the survival of their propagules or seeds (Fitriah et al., 2013). Unlike most land plants, mangrove propagules begin to germinate while still attached to their mother (viviparous). This allows the propagules to fall into the water in a ready-to-grow condition, where they can float for weeks until they find a suitable substrate to develop. With this adaptation, mangroves are able to survive in challenging environmental conditions and play an important role in maintaining the balance of coastal ecosystems.

Mangrove ecosystems are very complex because there is a reciprocal relationship between animals, plants and their environment. At the research location, various forms of morphological adaptations of mangrove plants were found, including the presence of supporting roots and breath roots. According to Nagelkerken et al. (2018) the breath roots of mangrove plants can stabilize the environment and provide many substrates for other plant and animal species. Supporting roots support the survival and ecological functions of mangroves, one of which is as a structural support that provides stability and strength for mangrove trees to survive in unstable environments, such as muddy soils and tidal areas. According to Katili et al. (2017) that mangrove roots can withstand material entering the mangrove forest, but the reduction of mangrove cover causes a reduction or even loss of mangrove roots, causing the nutrient-rich content in the mangrove to decrease.

The condition of mangroves in Paguyaman Pantai Subdistrict, still has a high density, with a relatively low level of damage. This is based on the facts of the analysis results presented in Table 4 of the research results section. Based on these results, the percentage of area (Ha) with mangrove vegetation density in the low category is 3.06%, the percentage of area (Ha) of mangrove vegetation density in the medium category is 39.95%, and the percentage of mangrove vegetation density area in the high category is 56.99%. This is in accordance with the facts obtained that in this area is dominated by mangrove vegetation with high density. It can be seen from the map (Figure 4) which is dominated by green color with an index value of 248.56 Ha, which means an area with high density. According to Susanto (2020), mangrove density shows the number of mangrove individuals in a certain area. Mangrove density refers to the number of individual mangrove trees that grow in a certain area, usually expressed in units of individuals per hectare (ind/ha) or individuals per square meter (ind/m2). The higher the number of trees in an area, the denser the mangrove ecosystem. A high density can indicate a healthy mangrove forest and is able to function optimally in protecting the coastline and providing habitat for various biota.

Mangrove ecosystems in Paguyaman Pantai sub-district are generally still in a healthy and maintained condition (Kawamuna et al., 2017). Only a small part of the area is degraded. NDVI analysis results show that a small part of the mangrove area in Paguyaman Pantai Sub-district is degraded, especially in the western part of Olibu Village and Apitalawu Village with relatively low vegetation index values of 1.76 and 1.07 Ha, respectively. Field validation indicated illegal logging activities and environmental pollution in the area. Meanwhile, in the eastern part of Limbatihu Village and Bubaa Village, mangrove degradation was recorded at 4.96 and 1.24 ha, respectively, due to exploitation of mangrove resources and land conversion into a port access road/special terminal (jetty) for the transportation of C-mining products. These areas are relatively small compared to the overall mangrove ecosystem that still dominates in good condition. Natural factors and human activities can indeed affect mangrove vegetation. According to Ilham et al. (2016), the ecological impact of reduced and damaged mangrove ecosystems is the loss of various species of flora and fauna associated with mangrove ecosystems, which in the long term will disrupt the balance of mangrove ecosystems in particular and coastal ecosystems in general. Naturally, changes in environmental conditions such as coastal abrasion, increased salinity, and climate change can accelerate the decline in mangrove quality. Meanwhile, human activities such as land conversion, illegal logging, and environmental pollution also worsen the condition of mangrove vegetation.

According to Chafid et al. (2012) these environmental disturbances include pollution by garbage, oil spills, and marine sand mining. On the other hand, Kanai et al. (2014) suggested that in addition to environmental disturbance factors, there are disturbances from varying salinity. When viewed based on its ecological functions, the first is storm wind dampening, abrasion prevention, mud retention and as a sediment trap, where it is much reduced. So, the next function, namely the second function as a producer of detritus is no longer visible in the mangrove environment that has decreased in area. Third, as an area of observation, the foraging and spawning area of fish and some other marine biota was reduced which resulted in decreased catches of fishermen.

4. Conclusions

The conclusions obtained from research on mangrove vegetation damage using remote sensing applications in the Paguyaman Pantai District are as follows: Based on the results of satellite image processing, the total area of mangrove ecosystems in Paguyaman Pantai District is 436.16 ha. Mangrove vegetation density is classified into three categories based on the NDVI (Normalized Difference Vegetation Index) value, namely: dense mangrove (>70%): 248 ha, moderate mangrove (30-70%): 174.23 ha, and sparse mangrove (<30%): 13.36 ha. The mangrove area in Paguyaman Pantai Sub-district as a whole is still dominated by mangroves with healthy conditions and high density. Thus, the condition of mangroves in general is still classified as good and still functions in maintaining the balance of coastal ecosystems. Damage to mangrove ecosystems in Paguyaman Pantai District does not occur on a small scale and is not dominant compared to areas that are still healthy, but only in certain areas that are degraded due to natural factors such as coastal abrasion and tides, as well as human activities such as land use change, illegal logging, and environmental pollution.

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The authors declare no conflict of interest.

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