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Mapping the Level of Mangrove Land Criticality using PlanetScope Imagery in Pesawaran Regency, Lampung

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ABSTRACT

Mangroves are vital to coastal ecosystems and benefits the environment. The Cuku Nyi Nyi and Petengoran mangrove ecosystems are among the ecosystems in Indonesia that have seen an increase in human activities, including the construction of fishponds and settlements, which have damaged the mangrove forests. As a result, the mangroves' functions are affected, including serving as a fortress against abrasion. To solve this issue, remote sensing is needed to map the condition of the mangrove forests. PlanetScope satellite imagery was chosen due to its high spatial resolution. There are three parameters to map this area's land criticality: land use, vegetation canopy density, and soil resistance to erosion. These three parameters were overlaid using the Weighted Overlay Analysis method to assess the criticality level of the mangrove ecosystem and the relevance of the parameters and methods used. The mapping results obtained three criticality classes: non-critical, critical, and very critical. It results in the three classifications of mangrove land criticality: Not Critical (198 ha), Critical (143.2 ha), and Very Critical (136.4 ha). Based on the classification, the Not Critical area are consists of mangrove close to the sea, the Critical Area is located further from the sea and consists of settlements, and the Very Critical Area is characterized by shrimp and salt ponds with low vegetation cover.

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1. INTRODUCTION

Mangroves are plants that form communities in tidal areas in coastal ecosystems with unique and distinctive characteristics and biodiversity (Ardiansyah and Safe'i, 2021). Mangrove trees are highly adaptable to environmental challenges, such as a lack of oxygen and high salinity (Kusumana, 2018). This plant also has solid roots and plays a vital role in maintaining the sustainability of the coastal ecosystem and providing great ecological benefits to the surrounding environment (Srikanth et al., 2015). A mangrove ecosystem is a system consisting of biotic and abiotic environments that interact in mangrove habitats (Alongi, 2015). The existence of mangrove habitats physically has benefits to maintaining the coastline and protecting the coast from abrasion, buffering the impact of storms and waves, and trapping sediments (Ersan et al., 2022), while the existence of mangrove habitats economically can increase community income through tourism activities.

Pesawaran Regency, Lampung Province, has mangrove habitats of various types. This district's mangroves include *Avicennia alba, Avicennia marina, Rhizophora apiculata, Rhizophora stylosa,* and *Soneratia alba* (Mutis, D., 2011). These types of mangroves have different characteristics. These types of mangroves provide various ecological, economic, and social benefits for the community in Pesawaran Regency (Anggriana et al., 2018; Mulya et al., 2021). Some of the locations where mangrove habitats exist in this district are the Cuku Nyi Nyi Mangrove Ecotourism Area in Sidodadi Village and the Petengoran Mangrove Forest in Gebang Village, Teluk Pandan District, Pesawaran Regency. Based on data obtained from the Dinas Kelautan dan Perikanan Kabupaten Pesawaran (2011) in 2007-2011, there has been an increase in the number of shrimp ponds by 32.23%, of which shrimp ponds in 2011 had an area of 77.96% that were intensively cultivated. The change in the use of mangrove land at the Pesawaran mangrove ecosystem into shrimp ponds in the coastal region of Pesawaran Regency by entrepreneurs, which is increasing from year to year, has resulted in a decrease in mangrove habitat and affects the resilience of mangroves to abrasion (Febryano et al., 2015). Therefore, from some of the conditions that have been explained earlier, mangrove land in the Cuku Nyi Nyi Mangrove Ecotourism Area and the Petengoran Mangrove Forest are critical.

The criticality of mangrove land clearly reflects the damage to mangrove forests at the research site (Iswahyudi et al., 2019). This criticality significantly impacts the environment and human life, particularly in terms of the loss of the function of mangrove ecosystems as a natural fortress against coastal abrasion. The lack of healthy mangroves led coastal area more vulnerable waves, flooding, and erosion, posing a direct threat to the sustainability of the surrounding settlements. Moreover, the criticality of mangrove land leads to habitat loss for various types of animals, including fish, birds, and invertebrates. This results in seawater intrusion into the land, loss of natural protection from wind and sea waves, and destruction of habitats of various types of fish, marine life, and other animals (Lampung Province Regional Environmental Management Agency, 2011).

Remote sensing is a vital technology for monitoring mangrove ecosystems, as it provides spatial data over wide and inaccessible coastal areas. It is effective in detecting canopy cover changes and mangrove degradation over time (Kamal et al., 2016). Mangrove vegetation displays unique spectral characteristics influenced by interactions between leaf, soil, and water reflectance, and is subject to tidal variations (Kuenzer et al., 2011; Kumar et al., 2017). The spectral reflectance in the Near-Infrared (NIR) range can vary between mangrove and non-mangrove vegetation, depending on chlorophyll structure and leaf cellulose (Zhang and Tian, 2013; Baloloy et al., 2020). High-resolution imagery like PlanetScope enables accurate

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identification of mangrove canopy based on spectral and textural patterns (Tran et al., 2022), making it a reliable tool for mangrove forest studies.

Damaged mangroves can reduce livelihood opportunities for communities that depend on these ecosystems, such as fishermen and pond farmers. In addition, the loss of mangrove ecosystem function causes a decrease in fish catches and significant economic losses for coastal communities. It also has the potential to increase conflicts between land uses and exacerbate regional social inequalities. Therefore, it is essential to conduct research that can help identify appropriate management strategies and provide a scientific basis for adequate regional mangrove protection and conservation policies.

Remote sensing technology can map the condition and composition of mangrove forests well, without requiring direct surveys in the field (Pham *et* al., 2019; Wijaya et al., 2023). PlanetScope remote sensing imagery with a high spatial resolution, namely 3-4 meters, can be used as an alternative data source for mangrove mapping. Planetscope remote sensing imagery is used because it has high spatial resolution and can map a wide variety of features, from common vegetation to shallow-water, vegetation such as seagrass (Wicaksono and Lazuardi, 2018; Roy *et al*., 2021). Furthermore, although (Qurniati et al., 2017) stated the condition of the mangroves in Sidodadi and Petengoran Villages is good, an intensive increase in shrimp ponds can disrupt the condition of the mangrove forest. Based on these conditions, comprehensive research is important to overcome the problem of mangrove land criticality and maintain the sustainability of mangrove ecosystems in the Pesawaran Regency area, Lampung, with the study area located in the Cuku Nyi Nyi Mangrove Ecotourism Area in Sidodadi Village, Petengoran Mangrove Forest in Gebang Village, and its surroundings.

2. METHODS

2.1. Research Site

This research is using PlanetScope Ortho Analytic 8B SR Level 3B Imagery, and it was conducted in the Cuku Nyi Nyi Mangrove Ecotourism Area in Sidodadi Village, Petengoran Mangrove Forest in Gebang Village, Padang Cermin District, Pesawaran Regency, Lampung Province, which is located at 525800 - 528100 mT and 9383700 - 9385900 mU with a zone of 48 M. The research was conducted at this location due to a decrease in mangrove habitat and an effect on the resistance of mangroves to abrasion. The decrease in mangrove habitat is mainly due to changes in the use of mangrove forest land for shrimp ponds. This research is based on three main parameters: land use type, canopy density, and soil resistance to abrasion.

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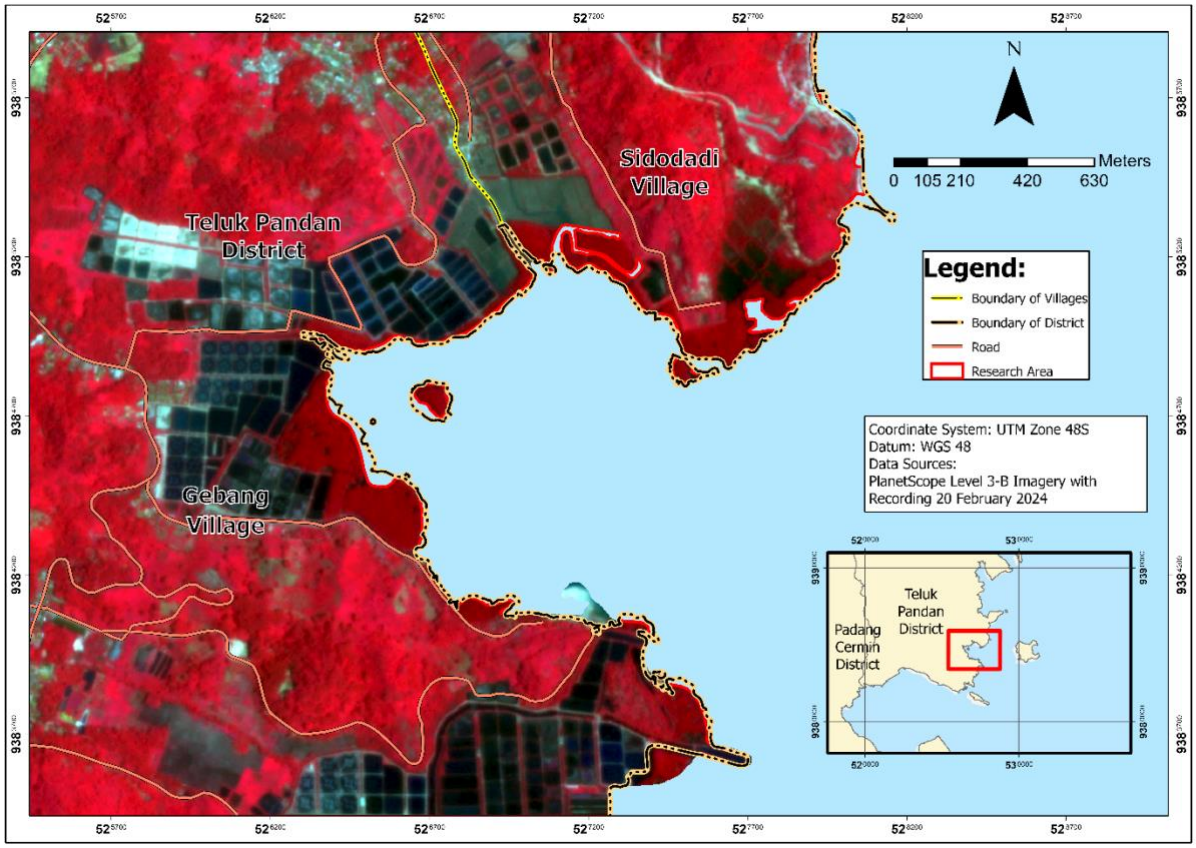


Figure 1. Study Area of Mangrove Land Criticality

2.2. Tools and Materials

This research will be supported using several tools and materials, including:

1) Tools:

- Laptop
- Image processing and analysis software (ENVI, ArcGIS)
- Statistical analysis software (SPSS)
- Microsoft Teams for reporting and collaboration
- Gap Light Analyzer (GLA)
- Fisheye lens and camera
- GPS handheld device
- Measuring tape and synthetic raffia rope
- Soil test kit
- Mangrove soil auger

2) Materials:

- PlanetScope Ortho Analytic 8B SR Level 3B imagery (recorded on February 20, 2024)
- Guidelines for the Inventory and Identification of Critical Mangrove Land (DoF, 2005)
- Field observation sheets

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2.3. Data Analysis

The main method used in this study was weighted overlay analysis. This analysis combined several parameters, such as canopy density, land use, and soil erosion resistance, to create a final map showing the importance of mangrove land critically in certain areas of Teluk Pandan subdistrict in the Pesawaran regency, which also includes the Cuku Nyi Nyi Ecotourism Area and the Petengoran Mangrove Forest.

2.3.1. Canopy Density Analysis

The analysis of mangrove canopy density was conducted using the Normalized Difference Vegetation Index (NDVI) transformation from PlanetScope imagery. The NDVI was then used to estimate vegetation density levels by considering the spectral response of reflectance in the red and near-infrared channels, which are sensitive to chlorophyll content and leaf cell structure, making them ideal for assessing canopy density levels. (Zhao et al., 2024; Pisyam, 2024). The NDVI calculation equation according to (Fern et al., 2018) is:

$$NDVI = (NIR-Red)\ (NIR+Red)$$

NDVI = *Normalized Difference Vegetation Index*
NIR = *Near-Infrared band* (band 8 on PlanetScope images)
Red = red wavelength band (band 6 on PlanetScope images)

The three classes used to classify the mangrove canopy density are based on the range of values generated from NDVI. The NDVI range ranges from -1 (non-vegetation) to 1 (vegetation), with a normal range for green vegetation ranging from 0.2-0.8 (Que et al., 2019). The score and weighting values refer to the Guidelines for Inventory and Identification of Critical Mangrove by the guidelines from Department of Forestry (2005). The classification of canopy density is divided into three classes, as shown in Table 1.

Table 1. Score and Vegetation Density Class

No	Score	Class
1	3	High Canopy Density
2	2	Medium Canopy Density
3	1	Low Canopy Density

Source: Department of Forestry, 2005

2.3.2. Land Use Analysis

Land use parameters are one of the main criteria used to assess the land critically. Land use classification is carried out visually using the on-screen digitization method according to the SNI-764-1:2024 standard. This method uses the interpretation of high-resolution satellite image, the appearance of objects in the images is essential for recognizing land use classes.

Land use types are classified into three categories, and the scoring system is based on national guidelines (Department of Forestry, 2005) and adapted to research conditions. These classes represent the level of land suitability, with the highest score is given to conditions that are most suitable for mangroves. Details of the classification, weights, and scores are presented in **Table 2**.

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Table 2. Class, Weight, and Score of Land Use Type

No	Class	Weight	Score
1	Land use type	43	a. 3: Forest b. 2: polyculture ponds, plantations c. 1: settlement, industry, non-intercropping ponds, paddy fields, vacant land

Source: Department of Forestry, 2005

2.3.3. Soil Resistance to Erosion Analysis

Soil resistance to abrasion analysis is used to evaluate a soil's ability to withstand erosion processes. Soil sensitivity to abrasion is defined as the ease with which soil erodes (Safira et el., 2023). In this study, soil sensitivity is classified into three categories based on texture, including: not sensitive (dominated by clay), sensitive (mixed), and highly sensitive (dominated by sand). The determination of classes, weights, and scores for this parameter is presented in **Table 3**.

Table 3. Class, Weight, and Score of Soil Sensitivity to Erosion

No	Class	Weight	Score
3	Soil Sensitivity to Erosion	**20**	a. 3: Clay texture b. 2: Mixed texture c. 1: Sandy texture

Source: Department of Forestry, 2005

2.3.4. Sampling Approach

This study employed a stratified purposive sampling method to determine observation sites within the study area. Stratified sampling considers strata or levels within a population (Arieska and Herdiani, 2018), which in this research refer to land units formed from the overlay of three land criticality parameters. Meanwhile, purposive sampling was applied based on specific considerations (Sugiyono, 2016) to facilitate sampling, enabling the selection of sites that align with the research objectives, variable characteristics for weighting, and field conditions. Using this approach, the samples were expected to represent land criticality conditions in accordance with the guidelines used. Two types of samples were collected: accuracy test samples, which validated the three mangrove land criticality parameters, and reinterpretation samples, which refined land use parameter boundaries to ensure greater accuracy in the final analysis maps.

2.3.5. Weighted Overlay Analysis

Weighted overlay analysis is a spatial analysis technique that integrates several thematic maps related to the factors that determine the critical level of mangrove land (Wismarini and Sukur, 2015). It involves assigning scores to each class of each variable and weighting them based on each variable's level of influence on critical land conditions (Faj'ri et al., 2024).

In this study, weighted overlay analysis integrates all the classified and scored parameters. Namely, land use type, canopy density, and soil resistance to abrasion. The scores and weights used in this analysis are adapted from national guidelines (Department of Forestry, 2005). The weighted overlay calculation is performed using the following formula:

$$Final_Score = \sum_{i=1}^{n} (Score_i \times Weight_i)$$

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In this formula, score i indicates the score value for parameter i and weight i is the weight for parameter i.

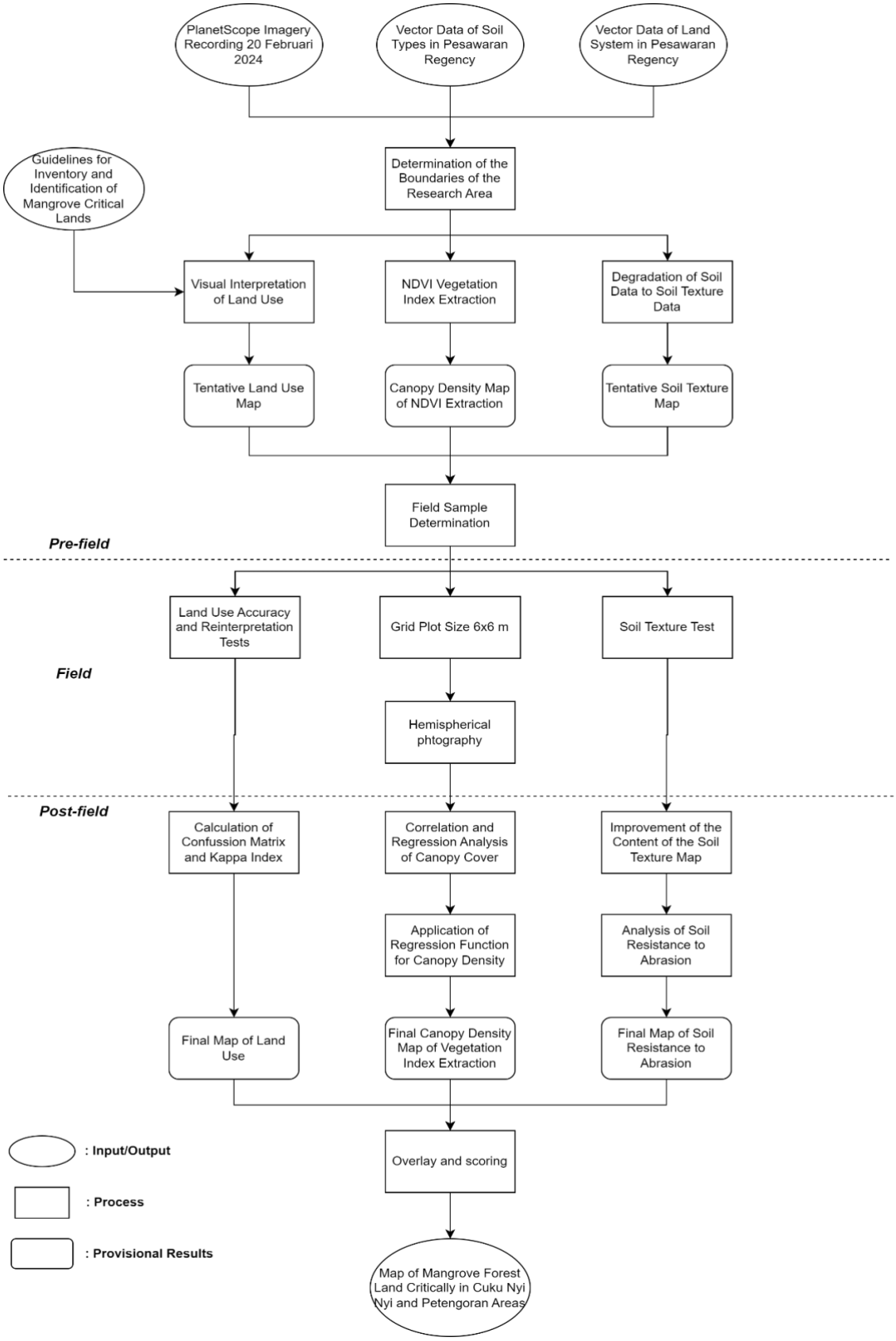


Figure 2. Flowchart of Research Methods

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3. RESULTS AND DISCUSSION

3.1. Land Use Types

Table 4. Score, class, and area of land use

Score	Class	Area (Ha)
3	Forest	58,7
	Mangrove forest	54,6
2	Mixed garden	6
	Cocoa cultivation	4,45
	Coconut cultivation	2,29
	Other cultivation	194,8
	Polyculture ponds	2,5
1	Village settlement buildings	27
	Other open land	0,8
	Open pit mining area	4,3
	Multi-crop rice fields	11,5
	Continuous rice paddy	4,2
	Shrubs	7,7
	Salt pond	5,4
	Shrimp ponds	109,4

Source: Data Analysis, 2024

One of the variables used as a determinant for calculating the level of land criticality is the type of land use (Kusuma and Buchori, 2021). Land use classification was conducted using PlanetScope imagery that was interpreted using the on-screen digitization method. In this case, the land use cover was classified into 15 classes that are shown in Table 4.

The identification of spatial use patterns is conducted by observing changes in land use over time. The greater the conversion of land from mangrove to non-mangrove areas, the higher the level of assessment, as mangrove land has been converted to settlements and ponds. Land conversion from mangroves to shrimp ponds causes several other damages, one of which is the waste generated. Waste generated from shrimp ponds is one of the things that affects the life of mangrove ecosystems, because the pH of the water used in shrimp ponds tends to be higher, so when the water is returned to the river, it can change the water quality, damage the health of mangrove plants, disrupt the soil structure, and disrupt the aquatic ecosystems that live in the area. These results are in line with research conducted by (Iber and Kasan, 2021), which states that waste produced from shrimp ponds results in a decrease in the quality of the surrounding water and an increase in ammonia content, which causes a decrease in soil quality and poisons organisms living around the ponds.

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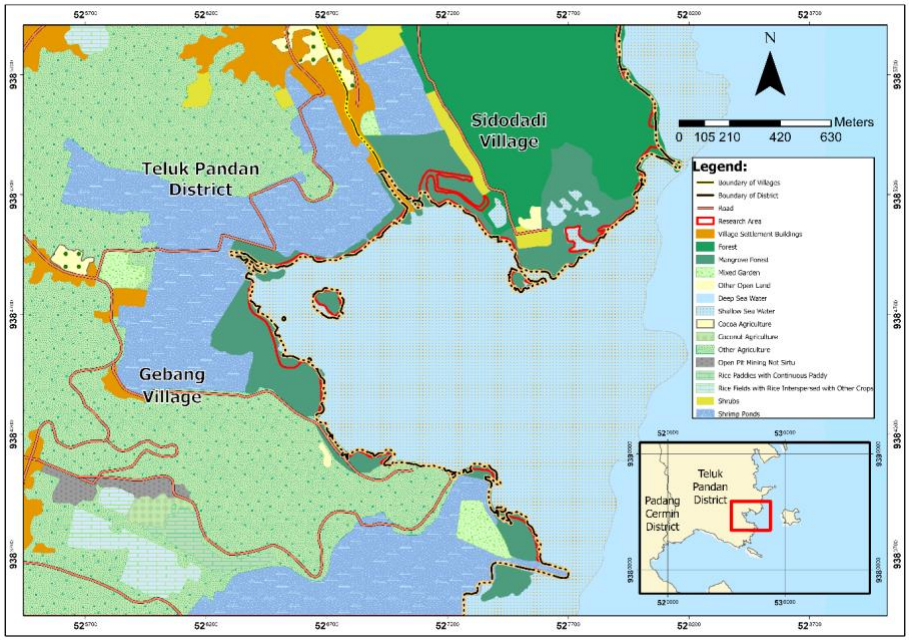


Figure 2. Map of Land Use and Land Cover

Based on the classification results obtained from the field data, we found that the largest plantation class is in Gebang and Sidodadi villages. Most of the shrimp ponds are located around the coast of Gebang Village, while the forest is primarily in Sidodadi Village. Mangrove areas are spread throughout the coast of Gebang and Sidodadi villages, each with a different area. The accuracy of the map was tested using the confusion matrix method, which compares the suitability of pre-field and field classifications. Based on the results of the accuracy test, the overall accuracy value of all samples taken was 58.41% with a kappa index of 0.49. This shows that the level of classification suitability on the map made is 68.41%. According to (Lestari et al., 2021), an accuracy value of more than 85% is required for the resulting model to be used as a reference in decision-making.**3.2. Canopy Density Value**

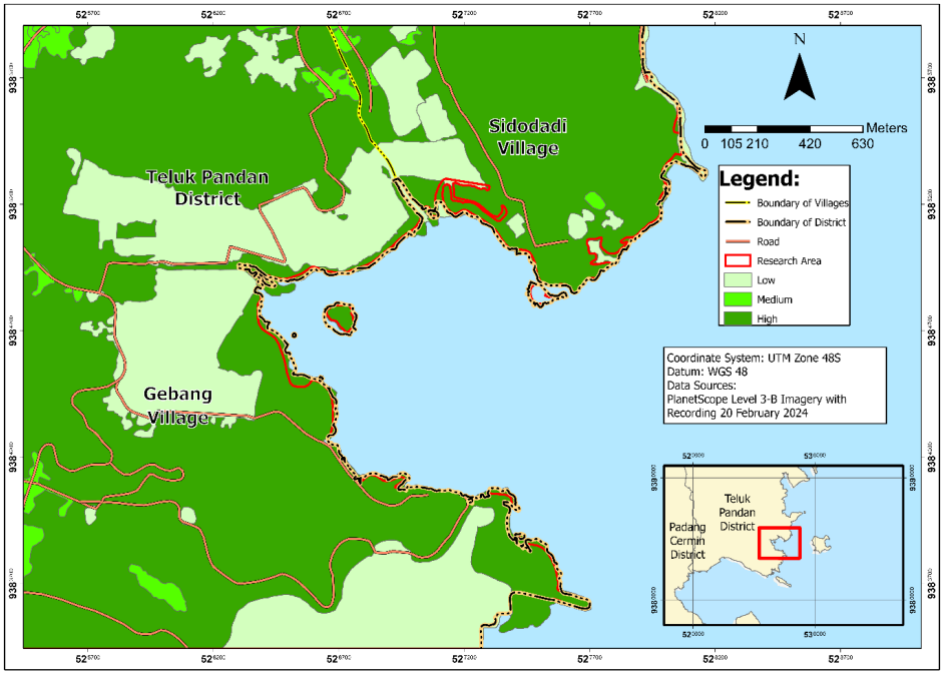


Figure 3. Map of Vegetation Density

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The determination of canopy density was conducted through several analysis stages. Initially, mangrove distribution was identified using PlanetScope Ortho Analytic 8B SR Level 3B imagery with band composition 8:6:4, which helps distinguish vegetation from non-vegetated areas. A supervised classification was then applied to differentiate mangrove vegetation, land, and water. Following this, NDVI (Normalized Difference Vegetation Index) was calculated using ArcGIS Raster Calculator. NDVI values were classified into three categories: high canopy density (0.43 – 1.00), medium canopy density (0.33 – 0.42), and low canopy density (-1.00 – 0.32).

Canopy density on the vegetation is accounted for using the vegetation index, which is NDVI, and then it is visualized in a map, which shows the distribution of the vegetation density classes: high, medium, and low. Based on the map, areas with high canopy density dominate the study area. The area calculation also resulted in high canopy density, as shown in Table 6. Most areas with high canopy density are in the mangrove forests, forests, and other agricultural areas. Meanwhile, vegetation density with a low canopy density class is found in shrimp ponds, salt, and rice fields.

Table 5. Score, Class, and Area of Vegetation Density

Score	Class	Area (Ha)
3	High Canopy Density	342,7
2	Medium Canopy Density	11,7694
1	Low Canopy Density	123,5087

Source: Field data, 2024

3.3. Soil Resistance to Erosion

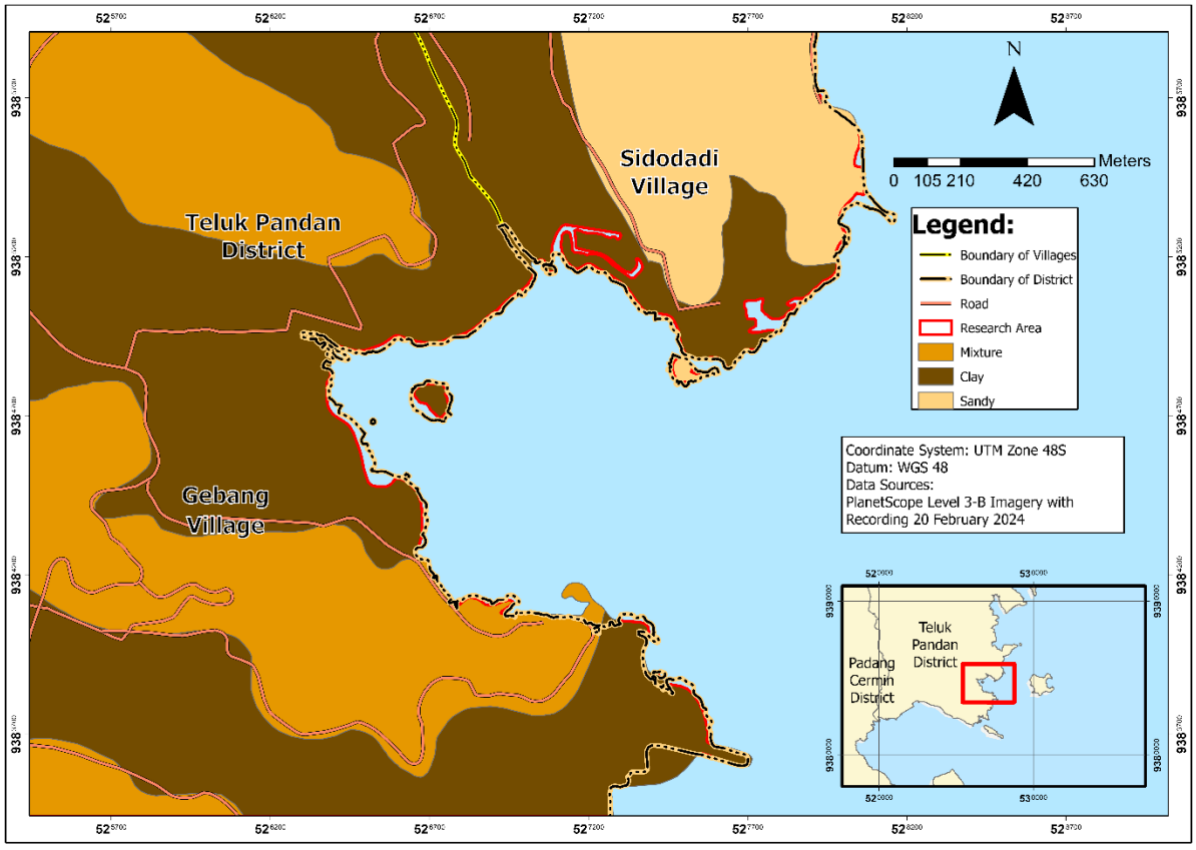


Figure 4. Map of Soil Texture Distribution

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The soil texture data obtained for each sample point were then plotted back into the study area map for visualization, resulting in the above map. It shows the distribution of three soil texture classes: clay, mixed, and sandy. The boundaries of each class are determined by the Land System Map. Based on the visual appearance of the map, the mixed and loamy (clay) textures are quite dominant because they are spread in almost all parts of Sidodadi Village and Gebang Village. Meanwhile, the sandy texture is found in the northeastern part of Sidodadi Village. Quantitatively, each class is represented in the form of an area that has units of hectares based on the following table.

Table 6. Score, Class, and Area of Soil Sensitivity to Erosion

Score	Class	Area (Ha)
3	Not Sensitive to Erosion (Clay)	256,9837
2	Erosion-Sensitive Soils (Mixed)	159,9376
1	Highly Erosion Sensitive Soils (Sand)	61,1249

Source: Data Analysis, 2024

Most of the study areas have non-erosion-sensitive soil in the form of loam, which has an area of 256.98 Ha. Furthermore, erosion-sensitive soil in the form of a mixture of sand and loam has an area of 159.94 Ha. And the last is highly erosion-sensitive soil in the form of sand, which has an area of 61.1249 Ha. The results of the analysis show that soils with clay texture are found in coastal areas, which include mangrove forest land use, shrimp ponds, some plantations, shrubs, rice fields, and settlements. Soils with mixed textures have uneven distribution and are mostly found in hilly areas that have land uses such as plantations and settlements. Meanwhile, sandy soils are found in the northeastern part of the study area, which has land use of forests and plantations, with a small portion of them also found in the mangrove land use of the Cuku Nyi Nyi Mangrove Ecotourism Area.

3.4. Critical Mangrove Area

Weighting and scoring methods are the best methods for determining the magnitude of every variable that is the object of this research. In research related to the level of mangrove land criticality, this is the last analysis of variables that have been classified by giving weight and scoring to each variable. The score and weighting values given refer to the Guidelines for Inventory and Identification of Critical Mangrove Lands by Department of Forestry in 2005, which included an assessment system with the help of GIS and remote sensing technology.

Based on the scoring system in Table 10, the total score value can be calculated using the formula below:

$$TSV1 = (LUT \times 45) + (HD \times 35) + (SRAA \times 20) \quad (1)$$

Based on TSV1, the level of mangrove criticality of the mangrove ecosystem can be determined:

Value 100–166: Severely damaged (very critical)

Value 167-233: Damaged (critical)

Value 234–300: Not damaged (uncritical).

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Table 7. Scoring system of mangrove land crisis

Criteria	Weight	Information
Land Use Type	45	Score 3: Wooded mangrove Score 2: Mixed ponds, plantations, and mangrove embankment Score 1: Settlement, industry, non-intercropping ponds, rice fields, and vacant land
Headline Density	35	Score 3: Dense canopy density (70-100% or 0,43 ≤NDVI≤ 1,00) Score 2: Medium canopy density (50-69% or 0,33 ≤NDVI≤ 0,42) Score 1: Sparse canopy density (<50% or -1,0 ≤NDVI≤ 032)
Soil Sensitivity to Erosion	20	Score 3: Not sensitive to erosion (clay texture) Score 2: Sensitive to erosion (mixed texture) Score 1: Very sensitive to erosion (sand texture)

Source Department of Forestry, 2005

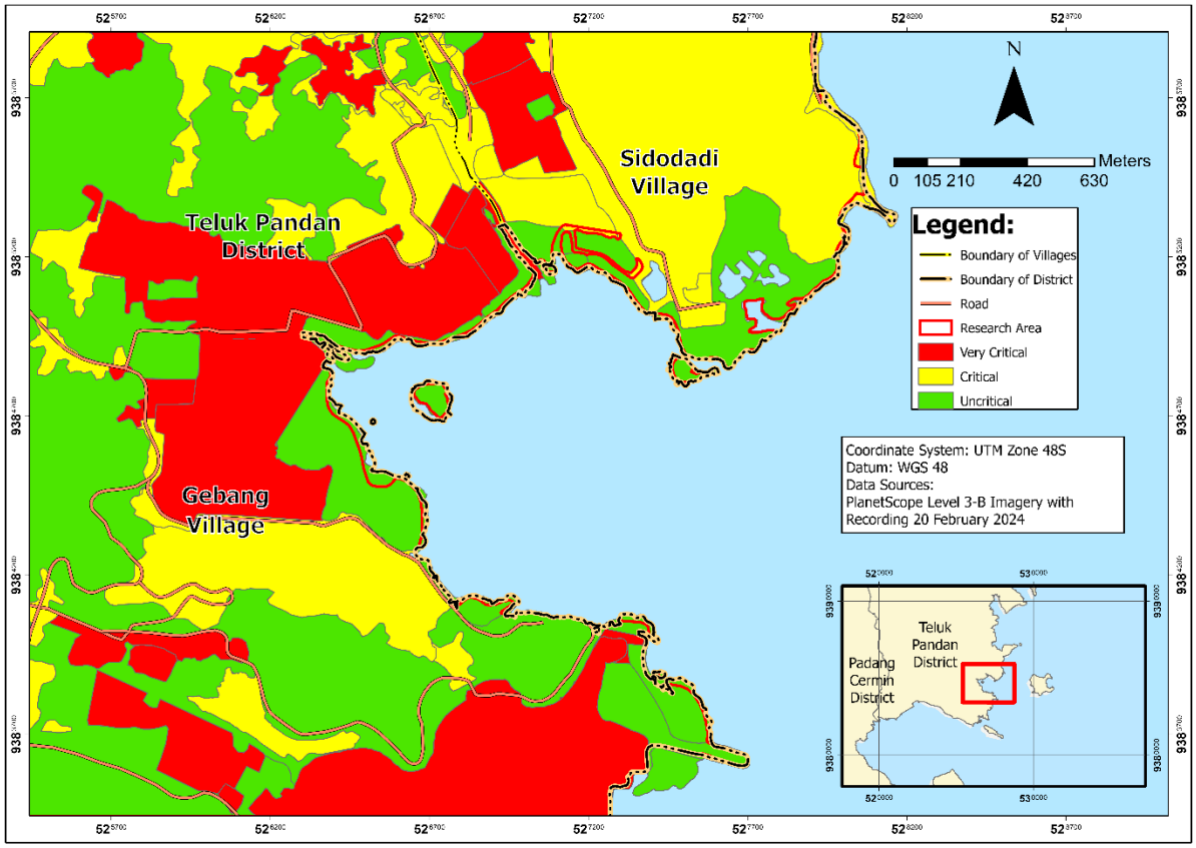


Figure 5. Map of Critical Level of Mangroves

Table 8. Score, Class, and Area of Land Criticality

Score	Class	Area (Ha)
100 - 166	Not critical	136,3267
167 - 233	Critical	143,2380
234 - 300	Very critical	198,2574

Source: Data Analysis, 2024

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The final mangrove land criticality model was formed from three main parameters, namely land use, mangrove canopy density, and soil texture, which were overlaid and scored into three classes: not critical, critical, and very critical. As shown in Table 8, the very critical class is the largest, which spreads along mangrove areas and hills that are quite far from the water. Critical becomes the second class with the highest area, which spreads far from the coastline and is dominated by residential land use with low to medium vegetation cover, with clay domination. The class with the smallest area is not critical, which is dominated by salt ponds and shrimp ponds with a small amount of vegetation cover and located next to the mangrove with a clay-textured soil type.

4. CONCLUSIONS

The study results showed that the criticality of mangrove land is determined by several parameters, including land use, mangrove canopy density, and soil resistance to erosion (soil texture). These parameters are assigned weights or values based on the national guidelines. The land use parameter has the highest weight. The next influential parameters are mangrove canopy density and soil texture. The calculation of the weight of the three parameters produces three classifications of mangrove land criticality: Not Critical covering an area of 198 ha, Critical covering an area of 143.2 ha, and Very Critical covering an area of 136.4 ha. Based on its distribution, the mangrove area directly adjacent to the sea has a normal condition or is not damaged. Each parameter used is assigned a weight, with three classes per parameter. Therefore, the mangrove area directly adjacent to the sea has a high weight value or is still in good condition.

In particular, critical areas (143.2 ha) are mostly located further inland and are dominated by mixed land uses such as settlements and low to medium vegetation cover. This class is highly vulnerable due to ongoing anthropogenic pressure and suboptimal vegetation recovery. Although the soil in these areas tends to have better erosion resistance (e.g., clay texture), the land cover and land use greatly reduce the ecosystem's resilience. The presence of moderate to sparse canopy density in these zones makes them particularly susceptible to further degradation if not properly managed. Therefore, these critical zones should be prioritized for rehabilitation before they transition into a very critical status.

Meanwhile, very critical areas (136.4 ha) exhibit the most degraded condition. These zones are mainly characterized by shrimp and salt pond land use with very minimal vegetation cover. Spatially, this class is often found behind mangrove stands, indicating a barrier zone that has lost its ecological function. Soil texture in these locations may still support mangrove growth, but the lack of vegetative cover and ongoing land conversion have pushed these areas to a severely degraded state. Immediate restoration interventions are necessary to prevent further ecological losses.

5. RECOMMENDATIONS

Mapping the critical level of mangrove land requires an ideal number of samples that can represent each class in the mapping unit. The ideal and representative number of samples for each class of mapping unit will produce a normal data distribution. Furthermore, sampling must be carried out randomly to ensure that the distribution of the resulting data is normal. Furthermore, mapping the ideal level of criticality of mangrove land requires a comprehensive and integrated approach. Starting from representative sampling, accurate data analysis, to the use of appropriate modeling methods, and community participation. All these factors must be considered to produce an accurate and useful map.

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