Mitigation of Mangrove Loss in Pasuruan City Based on the High-Resolution Image Spectral Index Method

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Abstract
This study aims to analyze the condition of mangroves in Pasuruan city, evaluate the suitability of mangrove land with spatial planning, and provide guidance for managing mangrove areas using spatial data. The methods used include the Mangrove Vegetation Index (MVI), overlay analysis between spatial plans and existing mangroves, and conservation strategies such as conservation, rehabilitation, and restoration. The results show that mangrove conditions from 2019 to 2023 have significantly declined. In 2023, the mangrove area decreased from 20.8 hectares to 15.3 hectares. Based on spatial planning, the areas deemed unsuitable are mostly located in the coastal ecosystem management zone, covering 24.8 hectares. As a result, rehabilitation should be prioritized, especially for areas that are severely damaged. The conservation zone is recommended to be at the end of Panggungrejo District, as this area still maintains relatively good mangrove conditions with optimal density. The originality of this study lies in the synthesis of MVI by combining high-resolution satellite imagery with spatial planning documents (RDTR and MTPP), creating a matrix-based conservation directive that classifies areas into zones for conservation, rehabilitation, and restoration.

Keywords: Degradation, Spectral Index, Mangrove Vegetation Index (MVI), Mitigation

1. Introduction

Mangroves are forest areas that grow between tidal lines, so mangrove forests are also called tidal forests. Mangroves can grow optimally in inundation conditions with surface water circulation, allowing for continuous sediment exchange and exchange, so mangrove forests are generally found on sandy or muddy beaches that are submerged in seawater sequentially and are affected by tides (Loupatty et al., 2023; Majid et al., 2016; Ramadhan et al., 2022). Ecologically, mangrove forests function as natural protectors of coastlines that protect coastal areas from the threat of abrasion and flooding. In addition, mangroves act as important habitats for various species of fish, mollusks, and invertebrates, which makes them a place to find food (feeding ground) and (nursery ground) (Ardhi Prasetyo Utomo et al., 2024). From an economic point of view, mangroves support the livelihoods of fishermen who depend on fisheries sustainability, as well as open up opportunities for tourism and conservation activities that can increase the income of the surrounding community.

The ecological, economic, and social benefits of mangrove ecosystems are very important for humans and the surrounding environment. However, various pressures from human activities threaten the sustainability of mangrove forests. The demand for new land for residential, commercial, industrial, and agricultural purposes has driven the conversion of mangrove areas into built-up areas (Nur et al., 2023). In addition, domestic waste disposal also results in damage to stake root in mangrove trees because domestic waste can reduce nutrient absorption, so that it can

kill the growth of mangrove trees (Dahuri et al., 2008; Purwoko et al., 2015). Lack of attention to sustainability aspects is the main factor that causes pressure on the current condition of mangrove forests, so mangrove management efforts are very important to maintain the sustainability of the mangrove ecosystem. Mangrove area management requires a spatial data-based approach to comprehensively map, analyze, and monitor ecosystem changes. The spatial data used in this study refers to the 2021 National Mangrove Map (PMN) data issued by the Coordinating Minister for Maritime Affairs and Investment, together with the Minister of Environment and Forestry, the Head of the Peat and Mangrove Restoration Agency (BRGM), and the Head of the Geospatial Information Agency (BIG). PMN in 2021 is a baseline of the current condition of mangrove areas that can be used as a basis for planning and policy-making in the context of mangrove ecosystem management.

Based on the 2021 PMN, the area of existing mangroves in Pasuruan City is 149.28 hectares with a rare to dense density level. However, Pasuruan City has experienced significant degradation of mangrove forests, both in terms of land and biodiversity . The degradation has occurred over the past 28 years with a percentage decline of around 20%, although the government has made various efforts, including the allocation of annual funds for mangrove forest conservation programs, the success rate is only around 50% (Harum et al., 2024). This shows that the measures taken have not been fully effective in addressing the damage that has occurred. If this degradation is left unchecked, the existence of mangroves will be threatened and can harm coastal areas.

The magnitude of the influence of degradation on the existence of mangroves can be analyzed through a remote sensing technology approach using satellite image data. Satellite imagery consists of several channels or bands that have a value based on the spectral wavelength emitted. The use of a vegetation index algorithm transformation is carried out to identify plants or plants such as mangroves. There are various algorithms used to determine the existence of mangroves, one of which is the mangrove vegetation index (MVI), which combines the NIR (Near Infra-Red) band, the SWIR (Short Wave Infra-Red) band, and the Green band (Yang et al., 2022). The results of the transformation of the spectral index of mangrove vegetation were adjusted to the spatial planning document to obtain directions for the development of mangrove area potential according to conditions in the field.

To optimize the development of the potential of mangrove areas in Pasuruan City, adjustments are needed to the development plan of the area and the region, especially in the related spatial plan. This adjustment is important to ensure that the development of mangrove areas does not conflict with the planned development direction. Similarly, it is necessary to provide an overview of coastal areas that should not become mangrove forests by considering the use of existing land and spatial pattern plans in the area. It is hoped that through these adjustments, the mangrove ecosystem area can develop sustainably and follow the spatial plan that has been set.

In line with this, there is a need for conservation recommendations that focus on efforts to maintain the sustainability and integrity of mangrove areas. The recommendations for the preservation of mangrove areas in Pasuruan City include strategies to protect intact mangrove

areas, rehabilitate degraded areas, and manage the use of mangrove resources wisely so as not to interfere with their ecological functions. This study aims to analyze the condition of mangroves in Pasuruan City from 2019 to 2023, analyze the suitability of mangrove land based on the spatial plan of Pasuruan City, and the direction of mangrove area management by utilizing spatial data.

2. Research Method

The area and location of the study of the use of spatial data in the management of mangrove areas is Pasuruan City, which consists of 4 sub-districts, including Bugulkidul District, Gadingrejo District, Panggungrejo District, and Purworejo District. The sub-districts in the coastal area are Bugulkidul District, Gadingrejo District, and Panggungrejo District. The data used are PMN in the form of a shapefile (.shp), Detailed Spatial Plan (RDTR) of Pasuruan City, and Sentinel-2 Level 2A satellite imagery.

Stages and Types of Research

This study uses a quantitative descriptive approach that uses a spatial approach to analyze conditions and provide directions for the management of mangrove areas in Pasuruan City. The purpose of this study is to identify the conditions and recommendations for mangrove area management based on the latest spatial data and satellite imagery.

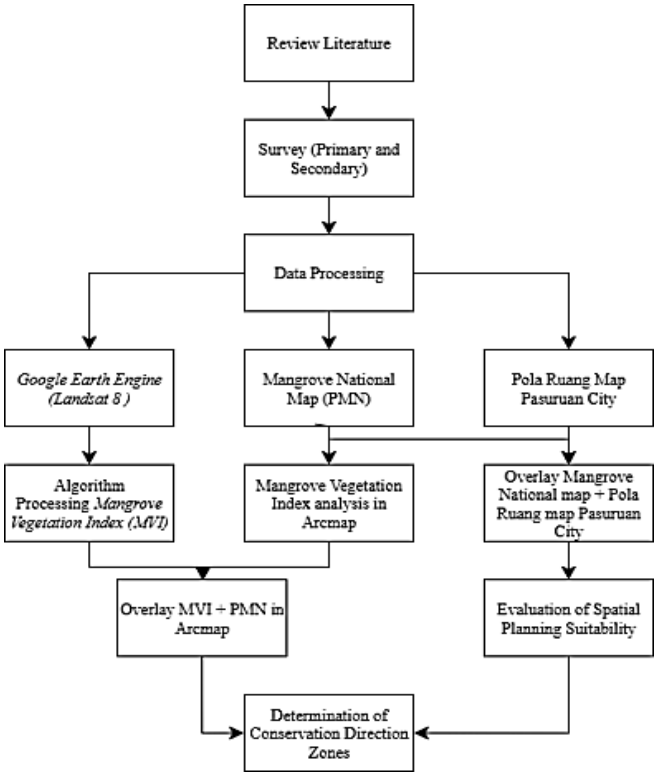

Figure 1. Overlay Techniques in Geographic Information Systems

Data Collection Methods

The research began with the collection of spatial data, which included Sentinel-2 satellite images, the 2021 National Mangrove Map (PMN), as well as spatial planning documents such as the Pasuruan City RDTR and Coastal Waters Technical Materials (MTPP). The next stage includes processing satellite images using Mangrove Vegetation Index (MVI) algorithms to identify and classify mangrove conditions based on the level of greenery and vegetation moisture. Furthermore, an overlay analysis was carried out between the existing mangrove map and the land and sea spatial pattern plan to evaluate the suitability of the spatial layout for the existence of mangroves. The results of this overlay analysis are used as a basis to establish a classification of management directions that include conservation, rehabilitation, and restoration, taking into account the combination of density and conditions of the mangroves that have been detected.

In this study, there are 2 types of data collected, namely Primary Data and Secondary Data, with data collection methods carried out using 3 techniques for primary data collection, namely observation, and interviews.

- **Observation**

  In supporting and verifying data for spatial analysis, field observations are carried out directly in the mangrove area of Pasuruan City. The purpose of this observation is to identify the real conditions of mangrove vegetation, evaluate the level of ecosystem damage, and observe anthropogenic activities that can indirectly affect the sustainability of mangrove ecosystems. Observations were also carried out to determine the suitability of existing mangroves with the zoning contained in the Detailed Spatial Plan (RDTR) and Coastal Waters Technical Materials (MTPP) documents.
- **Interview**

  The interviews were conducted to gather information from stakeholders directly related to the management, utilization, and preservation of mangrove areas in Pasuruan City. The purpose of the interview was to understand the perceptions, roles, constraints, and efforts made in developing a sustainable mangrove conservation strategy.

As for secondary data, it is carried out by literature review and data scraping:

- **Review Literature**

  The literature review in this study integrates scientific references (journals, research reports) and official technical/spatial documents (PMN, RDTR, MTPP) to compile the theoretical and methodological basis.
- **Scraping data**

  Data scraping is a digital method for retrieving essential data, such as data collected from websites or online portals, either manually or automatically. In this study, the online portals used are USGS (U.S. Geological Survey) and Google Earth Engine to acquire image data for the Pasuruan City.

Variabel

The variables used in this study are contained in Table 1.

Table 1. Research Variables

Variable	Type	Indicators/Measurements
Mangrove Density (PMN)	Spatial/Quantitative	Classification: Dense, Medium, Rare
Mangrove Conditions (MVI)	Spatial/Quantitative	MVI index value (3.47 – 16.950) and vegetation type
Spatial Pattern Suitability (RDTR & MTPP)	Spatial/Qualitative	Classification: Suitable, Unsuitable
Arahan Pelestarian	Spatial/Qualitative	Conservation, Rehabilitation, Restoration (PMN x MVI matrix results)

Source: Processed Research, 2025

Data Analysis Methods

Data analysis in this study was carried out using the mangrove vegetation index to obtain the classification value and change of mangroves from year to year. Then an overlay analysis and conservation direction was carried out based on a data matrix from mangrove density (PMN) and mangrove conditions (MVI), which resulted in directions in the form of Conservation, Rehabilitation, or Restoration. As explained below:

- **Mangrove Vegetation Index (MVI) Analysis**

  The data used are PMN in the form of a shapefile (.shp), Detailed Spatial Plan (RDTR) of Pasuruan City, and Sentinel-2 Level 2A satellite imagery. MVI (Mangrove Vegetation Index) is a vegetation index algorithm created and first introduced by Baloloy, A. B., et al. in 2020. MVI uses three spectral bands, namely SWIR1, NIR, and green, or bands 11,8 and 3, respectively, in the case of Sentinel-2 (Behera et al., 2021). NIR as a band is effective in indexing mangroves, because it is influenced by wet soil due to the tides of seawater. Then NIR was chosen as a band because of its ability to identify vegetation through the reflectance of mangrove species. The combination of the SWIR1, NIR, and green bands results in MVI (Baloloy et al., 2020).

  The MVI algorithm performed on the Sentinel-2 satellite imagery is said to be able to produce results with good accuracy even without using field sample data. The MVI algorithm is shown in the following equation:

$$MVI = \frac{(NIR - Green)}{(SWIR1 - Green)}$$

In the Sentinel-2 satellite imagery, the Near Infrared (NIR) wave is represented by band 8, the green wave by band 3, and the Short-wave Infrared (SWIR) by band 11. In the equation above, the section (NIR-Green) shows the difference in greenery level between mangroves and other vegetation. While the part (SWIR1-Green) shows the humidity of the mangrove area. This shows that MVI focuses on highlighting the level of greenery and humidity of mangrove forests, and distinguishing them from vegetation and other objects.

Because MVI is a new algorithm, until now, there are no standard guidelines or references for determining the class of mangrove density levels. Therefore, in this study, the determination of the mangrove density level class refers to a previous study conducted by Prayudha, B., et al. in 2021 (Prayudha et al., 2021). The study divided the density level of mangroves into four classes, which reflect the types of mangrove vegetation that exist. The range of index values used ranges from 3.47 to 16.950. The division of the types of mangrove vegetation can be seen in the following Table 2.

Table 2. The Value of The MVI Index for The Type of Mangrove

MVI Index Value	Types of Mangroves	Density
3.47 – 5.630	Undersstorey	Very Bad
5.631 – 6.690	Nypa	Bad
6.691 – 7.390	Mixed Mangrove	Good
7.391 – 16.950	Mangrove Trees	Very Good

Source: Prayudha et al., 2021

In the use of the mangrove type class, adjustments are made to the level of mangrove density. Types of mangrove trees (mangrove trees) represent an excellent level of density, where the vegetation canopy looks dense and dominates the mangrove area. Mixed mangrove types (mixed mangrove) show a good level of density, with a combination of several types of mangrove vegetation that provide a fairly solid canopy structure. Meanwhile, the type of nipa mangrove (N.Y.) reflects a poor degree of density, since the canopy is relatively sparse and less dominant. Mangrove understorey, which is at a very poor density level, is made up of small vegetation that grows under the main canopy or very close to the ground.

Although this classification does not fully reflect the actual density of mangroves, this estimate is quite representative based on the appearance of the vegetation canopy in satellite imagery. Classes with excellent density, such as mangrove trees, have a dense canopy and reflect healthy ecosystem conditions. In contrast, understorey mangroves, which have very poor density, are dominated by small vegetation such as Derris trifoliata and Acanthus ilicifolius, which are often used as indicators of degradation or damage to mangrove ecosystems (Ardli & Yani, 2020). The presence of these two species can

indicate a decrease in soil salinity levels, which is one of the main factors in mangrove degradation.

- **Overlay Analysis**

An overlay is one of the tools or the menu that is in the software (software) GIS is the ability to place a graphic of one map on top of another map graphic that aims to display the results on a computer layer or a plot (Fathan et al., 2019). In a nutshell Overlay is to overlap a map graphic on top of another map, along with the explanation of the attributes in it, and produce a combination of the two that has attribute information from the two maps.

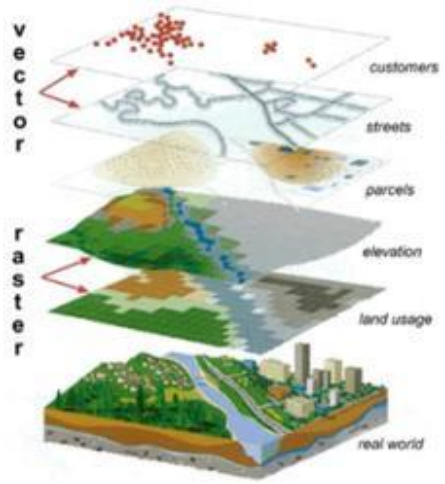

Figure 2. Overlay Techniques in Geographic Information Systems
Source: Fathan et al., 2019

In this study, the overlay method was used to identify the suitability between the existing mangrove area and the spatial pattern plan in the Pasuruan City Spatial Plan (RTR). The suitability of the spatial pattern plan with the mangrove area is an important effort to ensure that regional spatial planning (RTRW) is in line with the management of the mangrove ecosystem. The data used for this analysis are the Detailed Spatial Plan (RDTR) of the City of Pasuruan (Mayor Regulation Number 67 of 2021 concerning the Detailed Spatial Plan of the City of Pasuruan for 2021-2041) and the Coastal Waters Technical Material (MTPP) of East Java Province which regulates the pattern of marine space in East Java Province. To identify the suitability of the spatial pattern plan with the mangrove area, it is necessary to compare the land and sea spatial pattern plan of Pasuruan City and the existing mangrove area. This process results in two classifications, namely appropriate and inappropriate. The classification is appropriate if the area identified as an existing mangrove area is also listed as a mangrove area in the spatial pattern plan. On the other hand, the inappropriate classification applies if the area identified is not a mangrove area in the spatial pattern plan.

- **Analysis of the Conservation Directive Matrix**

The direction of mangrove area conservation was obtained through an overlay of two datasets, namely mangrove density data sourced from PMN and analysis results from MVI in the form of mangrove conditions. There are three types of mangrove density, including dense, medium, and rare mangroves. The condition of the mangroves from MVI is in the form of very good, good, bad, and bad conditions.

This directive is classified into three, namely Conservation, Rehabilitation, and Restoration. Conservation is aimed at mangrove areas that are dense and in good and excellent condition, with the aim of maintaining, protecting, and sustainably utilizing natural resources. Meanwhile, rehabilitation, which is the process of restoring the function of an ecosystem or land that has been damaged or degraded, is carried out on mangroves with moderate density and rarely in good condition. Meanwhile, restoration is carried out if mangroves are of moderate and rare density and in poor and very poor conditions in order to restore the damaged mangrove area to its original condition, with the condition before the damage.

3. Results and Discussion

The distribution of mangroves in Pasuruan City was identified based on the 2021 National Mangrove Map (PMN), which provides a detailed picture of the condition and distribution of mangrove ecosystems in the region. This data is used to map the area of existing mangroves, as well as a reference in analyzing the dynamics of growth and changes in mangrove vegetation over time. The following is the area of mangrove growth in Pasuruan City.

Table 3. Mangrove Distribution in Pasuruan City

District	Area (Ha)	(%)
Bug Kidul	103.03	69
Gadingrejo	6,06	4
Panggungrejo	40.20	27
Total	**149.2**	

Source: National Mangrove Map, 2021

Based on PMN data in 2021, all mangrove areas in Pasuruan City are naturally growing mangroves with an area of 152.9 hectares. Bugul Kidul District is the sub-district that has the highest mangrove area, which is 103 hectares or 69% of the total mangrove area in Pasuruan City.

Figure 3. Distribution of Mangroves in Pasuruan City
Source: National Mangrove Map, 2021

Mangrove Vegetation Index (MVI)

The results of the MVI analysis classified the condition of mangrove areas into four classifications, including mangrove areas with very good, good, bad, and very bad conditions. This data provides an overview of the dynamics of changes that occur in the mangrove ecosystem during this time frame, so that it can be used to evaluate the effectiveness of rehabilitation and conservation programs that have been implemented, as well as a basis for planning more sustainable mangrove management strategies in the future. The following is a classification of mangrove conditions with the MVI of Pasuruan City in 2019 and 2023.

Table 4. Mangrove Conditions with MVI Pasuruan City

Year	Very Bad	Bad	Good	Very Good
2019	7.4	3.6	2.3	20.8
2020	0.9	0.0	0.6	13.5
2021	2.5	3.2	1.1	22.6
2022	1.6	0.1	0.4	10.9
2023	6.6	4.2	2.7	15.3

Source: Landsat 8 lv 2 2019 - 2023

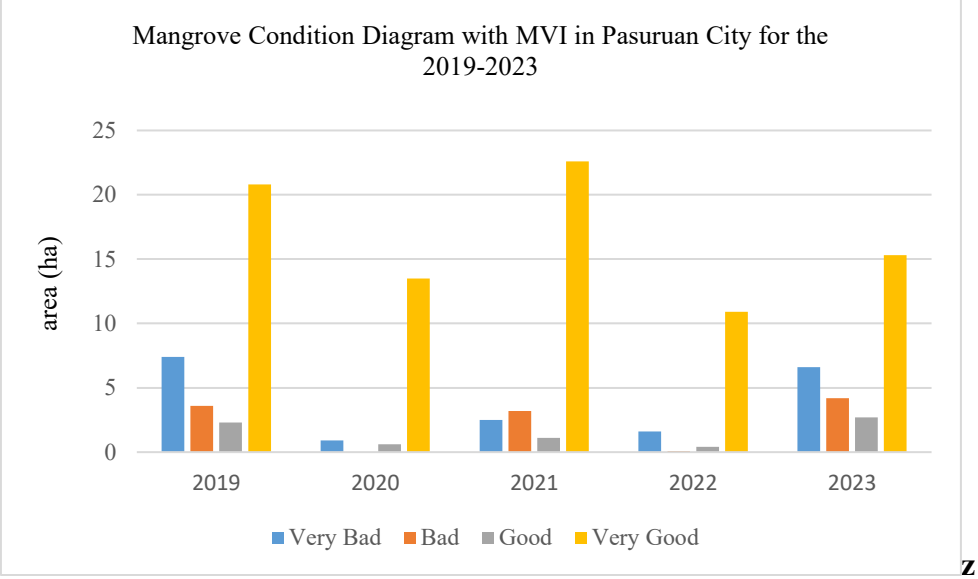

Figure 4. Diagram of Mangrove Condition with MVI in the Pasuruan City Area (2019-2023)
Source: Landsat 8 lv 2 Year 2019 – 2023

Based on the MVI analysis, it can be concluded that there are four classifications of mangrove conditions in Pasuruan City, namely very bad, bad, good, and very good. From 2019 to 2023, mangrove conditions tended to decrease, initially fell from 20.8 hectares in 2023 to 15.3 hectares. When viewed from the area, the condition of mangroves is very good, with the highest area in 2021, reaching 22.6 hectares, and in 2019, reaching 20.8 hectares.

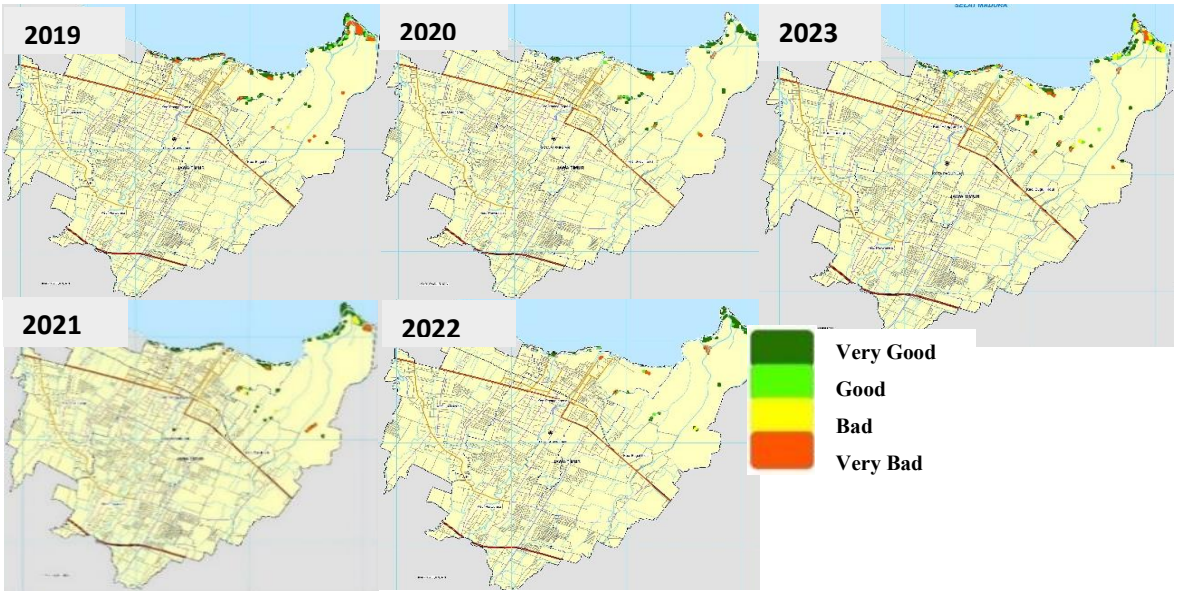

Figure 5. Map of Mangrove Conditions with MVI in Pasuruan City for the (2019-2023)
Source : Processed Products, 2025

Very good mangrove conditions reflect optimal vegetation density, indicating a healthy, stable, and productive ecosystem. Mangroves in these conditions show a strong ability to support their ecological functions, such as protection against coastal erosion, providing habitat for various types of fauna, and significant carbon sequestration. Mangrove trees that grow at an ideal distance from each other form a sturdy structure, allowing them to protect each other from strong winds, waves, and tidal waves. In addition, good density favors efficiency in the absorption of nutrients from soil substrates and the utilization of sunlight for the process of photosynthesis. This also ensures that mangroves can carry out their role as natural protectors of coastal areas while supporting the sustainability of the surrounding biodiversity.

Space Pattern Suitability

The suitability of the mangrove area can be processing with the spatial plan, some data is needed related to the applicable spatial plan, the spatial plan used, namely the land spatial pattern plan and the marine spatial pattern plan. In detail, it can be seen in the following description.

a. Land Space Pattern Plan in the Pasuruan City RDTR Number 67 of 2021

The plan for the land spatial pattern of the City of Pasuruan was obtained from Mayor Regulation Number 67 of 2021 concerning the Detailed Spatial Plan of the City of Pasuruan for 2021-2041. The spatial pattern plan of Pasuruan City consists of Water Bodies, Road Bodies, Power Reserves, Mangrove Ecosystems, Industrial Designation Areas, Tourism, Waste Management, Trade and Services, Local Protection, Defense and Security, Agriculture, Housing, Green Open Space, Non-Green Open Spaces, Public Service Facilities, and Transportation.

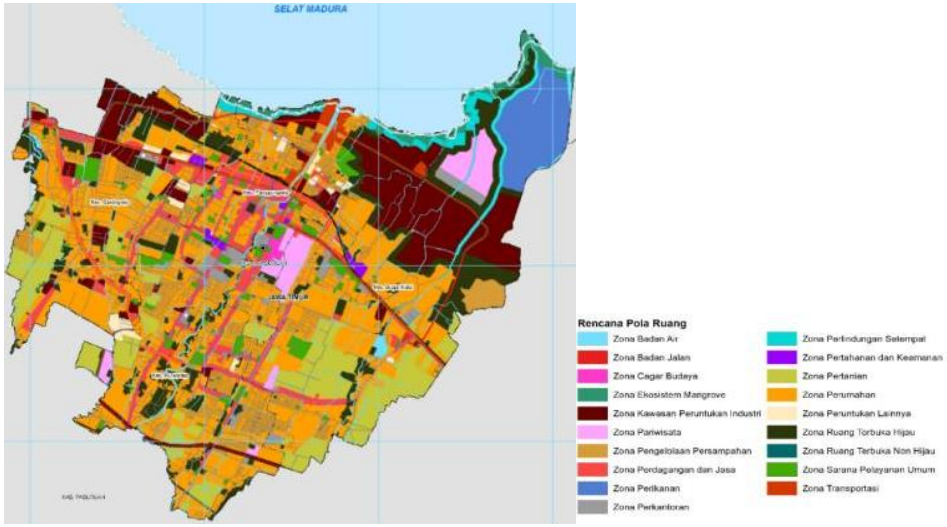

Figure 6. Pasuruan City Land Space Pattern Plan
Source: Mayor Regulation Number 67 of 2021 concerning the Detailed Spatial Plan of the City of Pasuruan for 2021-2041

b. Marine Space Pattern Plan in the East Java Province Coastal Waters Technical Material (MTPP) document

The marine space pattern was obtained from the East Java Province Coastal Waters Technical Material (MTPP) document. The plan for the marine space pattern of Pasuruan City consists of three zones, namely the Sea Port Zone, the Coastal Ecosystem Management/Blue Carbon Reserve Zone, and the Capture Fisheries Zone.

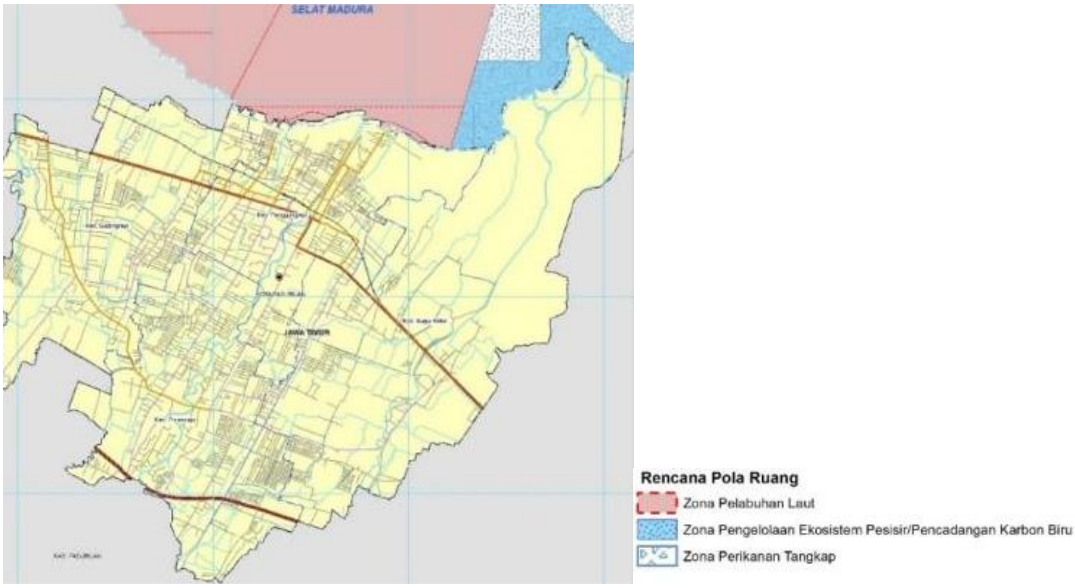

Figure 7. Pasuruan City Marine Space Pattern Plan
Source: Coastal Waters Technical Material of East Java Province

The seaspace pattern plan and the land-based space pattern plan, then carried out in mangrove areas. This aims to see the suitability between the existing mangrove area and the applicable spatial plan. Results of the Overlay can be seen in the following Table 4.

Table 1. Suitability of the Land and Sea Space Pattern Plan of the Mangrove Area

Suitability of Space Pattern Plan	Space Pattern Plan	Zone/Sub Zone	Area (Ha)	Percentage
Appropriate	Land Space Pattern Plan (Guardian Regulation No. 67 of 2021 concerning the Pasuruan City	Mangrove Ecosystem	58.32	39.06%

Suitability of Space Pattern Plan	Space Pattern Plan	Zone/Sub Zone	Area (Ha)	Percentage
	RDTR for 2021-2041)			
Inappropriate	Land Space Pattern Plan (Guardian Regulation No. 67 of 2021 concerning the Pasuruan City RDTR for 2021-2041)	Water bodies	4.46	2.99%
		Road Body	0.74	0.50%
		Green Lane	0.64	0.43%
		Industrial Allocation Area	14.34	9.61%
		Tourism	4.57	3.06%
		Aquaculture Fisheries	10.08	6.75%
		Perkantoran	1,25	0,84%
		Local Protection	9.49	6.36%
		Medium Density Housing	0.47	0.31%
		City Park	8.06	5.40%
		Transportation	4.00	2.68%
	Marine Space Pattern Plan (MTPP 2018-2038) East Java Province	Sea Port Zone	7.94	5.32%
		Coastal Ecosystem Management Zone	24.80	16.61%
		Coastal Ecosystem Management/Blue Carbon Reserve Zone	0.12	0.08%
Total Amount			**149.28**	**100%**

Source: Mayor Regulation Number 67 of 2021 concerning the Detailed Spatial Plan of the City of Pasuruan for 2021-2041 and Coastal Waters Technical Material (MTPP) of East Java Province for 2018-2038

Based on the table, information can be obtained that the land and sea spatial pattern plans that intersect with the mangrove area of Pasuruan City amount to 15 spatial pattern plans. Most of these plans are not by the existence of existing mangrove areas. Only the spatial pattern plan of the mangrove ecosystem area is in accordance with an area of 58.32 hectares. When viewed from the area, most of the areas that are not suitable are in the coastal ecosystem management zone, with an area of 24.80 hectares.

From each spatial pattern plan in Table 4, the general provisions of the regulations of each subzone of the land spatial pattern plan subzone are seen from Mayor Regulation Number 67 of 2021 concerning the Detailed Spatial Plan of the City of Pasuruan for 2021-2041. This aims to determine whether the spatial pattern plan is permitted, permitted with limitations, or not permitted for the development of mangrove areas.

Table 5. Outline of the Direction for the Utilization and Development of Mangrove Areas

Instructions	Area (Ha)	Percentage (%)
Allowed	105.89	71
Limited/Conditional	28.31	19
Not Allowed	15.08	10

Source: Analysis Results, 2025

Based on the data above, information can be obtained that mangrove areas in Pasuruan City are mostly allowed for mangrove area development activities, with an area of 105.89 hectares or 71% of the total area of the mangrove area of Pasuruan City. This area includes a plan for water body spatial patterns, mangrove ecosystems, green pathways, local protection, and coastal ecosystem management zones. Meanwhile, the area with limited/conditional directions is 28.31 hectares and is not allowed within an area of 15.08 hectares.

3.1 Direction For The Preservation of Mangrove Area in Pasuruan City

The direction of the conservation of the mangrove area in Pasuruan City is based on the matrix between mangrove density and mangrove conditions. The conservation directions are categorized into three, of which are conservation, rehabilitation, and restoration. The matrix can be seen in detail in the following table.

Table 6. PMN Matrix and MVI Analysis

	Very Good	Good	Bad	Very Bad
Lush Mangroves	Conservation	Conservation	Rehabilitation	Restoration
Medium Mangrove	Rehabilitation	Rehabilitation	Restoration	Restoration
Rare Mangrove	Rehabilitation	Rehabilitation	Restoration	Restoration

Source: Analysis Results, 2025

Based on this matrix, a number of strategic directions were obtained that can be guidelines for conservation efforts in Pasuruan City. The directive includes several directives designed to maintain environmental sustainability and improve the quality of mangrove areas. The conservation directions in question are as follows:

Table 7. Direction for the Preservation of Mangrove Areas

Referral	Area (Ha)
Conservation	0.21
Rehabilitation	16.61
Restoration	10.18

Source: Analysis Results, 2025

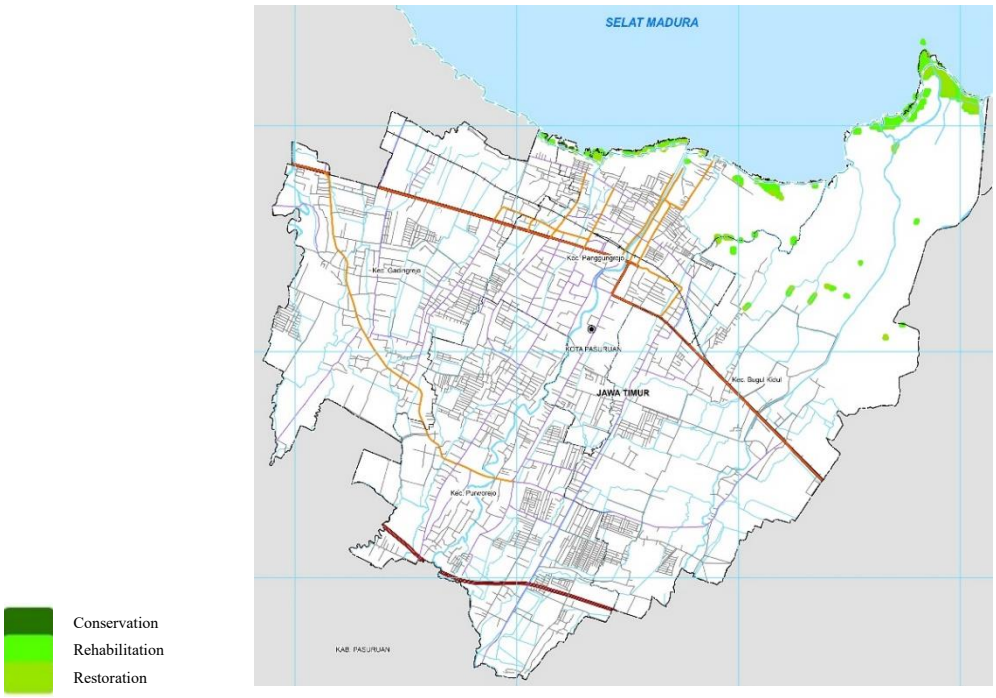

Figure 8. Direction for the Preservation of Mangrove Areas
Source: Analysis Results, 2025

Based on the table above, it is obtained that Pasuruan City has three directions, namely, Conservation, Rehabilitation, and Restoration. In terms of area, 16.61 hectares need to be rehabilitated because they have a moderate density (PMN, 2021) and are rare, but mangrove conditions are good (MVI, 2024). If you look at the distribution, it can be seen that the conservation direction is in Panggungrejo District. This indicates that the sub-district has mangroves with high density and in very good condition. Rehabilitation and restoration directives. located along the coast of Pasuruan City and at the pond of Bugul Kidul District.

4. Conclusion

Pasuruan City has a mangrove area of 149.28 hectares, where Bugul Kidul District has the largest mangrove area of 103.03 hectares. Mangrove conditions vary from very good to the opposite, with a downward trend in the area in the "very good" category from 2019 to 2023, from 20.8 hectares in 2023 to 15.3 hectares. In addition, only 39.06% of the mangrove area is in

accordance with the spatial plan that has been set, so it is necessary to harmonize with the spatial layout by considering the ecological condition of mangrove plants.

Mangrove management directions include conservation, rehabilitation, and restoration, with rehabilitation being a top priority. The conservation area is located at the end of Panggungrejo District, because the mangrove area in this area tends to have very good conditions and a good density. These conservation efforts are aimed at maintaining the ecological function of mangroves, such as protection against abrasion, habitat provision, and carbon storage. Excellent mangrove conditions indicate a healthy and productive ecosystem, but pressures from human activities and spatial inconsistencies remain a major challenge.

Therefore, sustainable mangrove management requires an integrated approach through better spatial planning, regulatory strengthening, and extensive rehabilitation. This strategy not only supports the preservation of mangrove ecosystems but also contributes to the protection of the coastal environment and the livelihoods of the surrounding community. Collaboration between the government, the community, and other stakeholders is very important to realize the conservation of mangroves in Pasuruan City in a sustainable manner.

References

Ardhi Prasetyo Utomo, Jamilah Okta Haerani, Rio Nur Ferdian, Risqika Paradise, & Denny Oktavina Radianto. (2024). Maximizing the Function of Mangrove Planting in Abrasion-Prone Areas of Jakarta. *Nusantara Scientific Journal*, *1*(3), 12–22. https://doi.org/10.61722/jinu.v1i3.1502

Ardli, E. R., & Yani, E. (2020). Mangrove Damage Evaluation using Two Species of Acanthus as a Biomonitoring Agent, Case Study: Segara Anakan Cilacap, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *550*(1), 012001. https://doi.org/10.1088/1755-1315/550/1/012001

Baloloy, A. B., Blanco, A. C., Sta. Ana, R. R. C., & Nadaoka, K. (2020). Development and application of a new mangrove vegetation index (MVI) for rapid and accurate mangrove mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, *166*, 95–117. https://doi.org/10.1016/j.isprsjprs.2020.06.001

Behera, M. D., Barnwal, S., Paramanik, S., Das, P., Bhattyacharya, B. K., Jagadish, B., Roy, P. S., Ghosh, S. M., & Behera, S. K. (2021). Species-Level Classification and Mapping of a Mangrove Forest Using Random Forest—Utilisation of AVIRIS-NG and Sentinel Data. *Remote Sensing*, *13*(11), 2027. https://doi.org/10.3390/rs13112027

Dahuri, R., Rais, J., Putra Ginting, S., & Sitepu. (2008). *Integrated Management of Coastal and Marine Resources*.

Ely, A. J., Tuhumena, L., Sopaheluwakan, J., & Pattinaja, Y. (2021). Mangrove Forest Ecosystem Management Strategy in the Country of Amahai. *Triton: Journal of Aquatic Resources Management*, *17*(1), 57–67. https://doi.org/10.30598/TRITONvol17issue1page57-67

Fathan, M., Sukmono, A., & Firdaus, H. S. (2019). *Analysis of Land Suitability of Forestry and Agricultural Commodities in the Semarang Regency Region with the Matching Method*. *Sec. 8*.

Guntara. (2013). *Definition of Overlay in Geographic Information Systems*. https://www.guntara.com/2013/01/pengertian-overlay-dalam-sistem.html

Idrus, A. A., Ilhamdi, M. L., Hadiprayitno, G., & Mertha, G. (2018). Socialization of the Role and Function of Mangroves in the Community in the Gili Sulat Area, East Lombok. *Journal of Master of Science Education Service*, *1*(1). https://doi.org/10.29303/jpmpi.v1i1.213

Loupatty, S. R., Haumahu, S., Ardiansyah, A., & Mailoa, M. N. (2023). Composition of mangrove types in Dokyar Hamlet, Kaibobu Village, West Seram Regency. *Biopendix: Journal of Biology, Education and Applications*, *9*(2), 242–254. https://doi.org/10.30598/biopendixvol9issue2page242-254

Majid, I., Al Muhdar, M. H. I., Rohman, F., & Syamsuri, I. (2016). Mangrove forest conservation on the coast of Ternate City is integrated with the school curriculum. *Journal of Bioeducation*, *4*(2). https://doi.org/10.33387/bioedu.v4i2.162

Manna, S., & Raychaudhuri, B. (2020). Mapping distribution of Sundarban mangroves using Sentinel-2 data and a new spectral metric for detecting their health condition. *Geocarto International*, *35*(4), 434–452. https://doi.org/10.1080/10106049.2018.1520923

Mattone, C., & Sheaves, M. (2024). Mangrove forest ecological function is influenced by the environmental settings and the benthic fauna composition. *Estuarine, Coastal and Shelf Science*, *309*, 108959. https://doi.org/10.1016/j.ecss.2024.108959

Muhammad, D., Tanjung, F. A. M., & Harum, N. S. (2024). *Analysis of Mangrove Damage in Pasuruan City Using Satellite Image Data*.

Muryani, C. (2010). Analysis of Shoreline Changes Using GIS and Its Impact on Community Life Around the Mouth of the Rejoso River, Pasuruan Regency. *Geography Forum*, *24*(2), 173. https://doi.org/10.23917/forgeo.v24i2.5024

Muryani, C., Ahmad, Nugraha, S., & Utami, T. (2011). *Model of Community Empowerment in the Management and Preservation of Mangrove Forests on Pasuruan Beach, East Java*.

Nagelkerken, I., Blaber, S. J. M., Bouillon, S., Green, P., Haywood, M., Kirton, L. G., Meynecke, J.-O., Pawlik, J., Penrose, H. M., Sasekumar, A., & Somerfield, P. J. (2008). The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquatic Botany*, *89*(2), 155–185. https://doi.org/10.1016/j.aquabot.2007.12.007

Nur, F. A., Permatasari, N. S., & Nurliana, M. (2023). *Utilization of Mangrove Ecosystems for the Survival of Coastal Communities in Tanjung Rejo Village, Percut Sei Tuan District, Deli Serdang Regency, North Sumatra*.

Prayudha, B., Siregar, V., Ulumuddin, Y. I., Suyadi, Prasetyo, L. B., Agus, S. B., Suyarso, & Anggraini, K. (2021). The application of Landsat imageries and mangrove vegetation index for monitoring mangrove community in Segara Anakan Lagoon, Cilacap, Central Java. *IOP*

Conference Series: Earth and Environmental Science, *944*(1), 012039. https://doi.org/10.1088/1755-1315/944/1/012039

Purwoko, P. F., Wulandari, A. A., Benariva, A. P., Tiara, A., Sabiel, M. Q. T., Risaandi, R., Jannati, A., Nugraha, A., Noriko, N., & Priambodo, T. (2015). *Vegetation Resilience of the Mangrove Area of the Muara Angke Wildlife Sanctuary, DKI Jakarta to Garbage from River Streams*.

Ramadhan, D. A., Hasibuan, F. U., Damayanti, D., & Amalia, T. (2022). Public perception of Kuala Langsa Mangrove Forest Ecotourism. *Journal of Community Service Biology and Science*, *1*(2), 7–14. https://doi.org/10.30998/jpmbio.v1i2.1079

Whitfield, A. K. (2017). The role of seagrass meadows, mangrove forests, salt marshes and reed beds as nursery areas and food sources for fishes in estuaries. *Reviews in Fish Biology and Fisheries*, *27*(1), 75–110. https://doi.org/10.1007/s11160-016-9454-x

Winarso, G., Purwanto, A. D., & Yuwono, D. M. (2014). *New Mangrove Index As Degradation/Health Indicator Using Remote Sensing Data : Segara Anakan And Alas Purwo Case Study*.

Zurba, N., & Effendi, H. (2017). Management of Mangrove Ecosystem Potential in Kuala Langsa, Aceh. *Journal of Tropical Marine Science and Technology*, *9*(1).