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Mangrove Vegetation Condition Based on Mangrove Canopy Cover Distribution in, Rembang Regency, Central Java, Indonesia

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Abstract

Mangrove vegetation plays an important role in maintaining the balance of coastal ecosystems, yet its existence is increasingly threatened by human activities. Rembang Subdistrict is one of the areas affected by these threats. This study aims to analyse the condition of mangrove vegetation based on canopy cover using the NDVI (Normalized Difference Vegetation Index) in three coastal villages of Rembang Subdistrict: Pasar Banggi, Tireman, and Kabongan Lor. NDVI is suitable for mangrove analysis because it sensitively reflects vegetation density and health, allowing accurate detecteion of mangrove conditions. Canopy cover distribution was obtained from the processing of Sentinel-2A satellite imagery acquired in September 2024 with standard corrections. The mangrove vegetation condition was determined based on the guidelines for inventory and identification of critical land by the Ministry of Forestry (2005). The results show that NDVI values ranged from 0.2 to 0.6, indicating variations from sparse to dense mangrove cover. Such variation suggests localized degradation patterns within the mangrove ecosystem. Further research is needed to enrich the data and serve as a guide for mangrove area development in Rembang Subdistrict.

1. Introduction

Mangrove vegetation, along with seagrass beds and coral reefs, is one of the key coastal ecosystems and plays a crucial role in supporting surrounding ecosystems and the organisms that inhabit them (Hasim, 2021). Mangrove vegetation is vital for maintaining the stability of coastal ecosystems, serving as a natural barrier against abrasion, a habitat for marine life, and a carbon sink (Maryani *et al*., 2025). Global assessment emphasize the critical role of mangroves in carbon storage and coastal protection, while also reporting significant declines due to human and climate pressures (FAO, 2020; IPCC, 2022). However, pressures from human activities such as land conversion, illegal logging, and infrastructure development have led to the degradation of mangrove vegetation in various coastal areas of Indonesia (Hidayat and Rachmawatie, 2021). Recent assessment indicate that Indonesia has lost 24% of its mangrove cover the past three decades, largely due to aquaculture expansion and coastal development (FAO, 2020; KLHK, 2021). Monitoring the condition of mangrove vegetation is an essential step in conservation and rehabilitation efforts. One of the key indicators for assessing mangrove is canopy cover, which reflects the health and density of the vegetation (Putra *et al*., 2025).

Rembang Subdistrict has a relatively extensive coastal area with mangrove ecosystems distributed across several villages, including Pasar Banggi, Tireman, and Kabongan Lor. These three villages have significant areas of both natural and rehabilitated mangroves covering approximately 60 hectares in total, but they are under pressure from aquaculture and residential activities. Historically, Pasar Banggi had about 45 hectares of mangrove forest (Wibowo *et al.*, 2022), Tireman had 10 hectares in 2018 representing a decrease of 3 hectares since 2013 (Laraswati *et al.*, 2020), while data for Kabongan Lor are not yet available. They represent the general condition of mangroves in Rembang

Subdistrict and serve as key focus areas for mangrove development in Rembang Regency, as outlined in the Regional Spatial Plan (RTRW) of Rembang Regency under Regional Regulation No. 2 of 2023.

One of the methods used to analyse the condition of mangrove vegetation is by utilizing satellite imagery and vegetation indices such as NDVI (Normalized Difference Vegetation Index) (Fahreza *et al*., 2022). NDVI can reflect the greenness and canopy density of vegetation based on the light reflectance from plant surfaces. NDVI analysis is an effective tool for identifying areas in good condition as well as those in need of rehabilitation (Istomo *et al*., 2025). Therefore, analysing canopy cover through NDVI is important for understanding the spatial distribution and quality of mangrove vegetation (Iman *et al*., 2024). Although many studies have addressed mangrove mapping and NDVI analysis, few have specifically linked NDVI values to mangrove vegetation condition at the village level in detail. Previous studies in Indonesia have generally assessed mangrove conditions at broader spatial scales. For Instance, Giri *et al.* (2011) mapped mangrove distribution across the country using Landsat data, at provincial level, Arifanti *et al.* (2019) reported patterns of mangrove loss and degradation in Kalimantan and Sumatra. Previous research has also rarely addressed variations between small areas such as those in Rembang Subdistrict. Moreover, canopy based mangrove vegetation condition data to support local policy making remains limited.

This study addresses the lack of detailed canopy and vegetation condition data at the village level in Pasar Banggi, Tireman, and Kabongan Lor. Therefore, this study aims to analyse the condition of mangrove vegetation based on canopy cover values using the NDVI. The results of study are expected to serve as a foundation for mangrove management and conservation efforts in Rembang Subdistrict.

2. Material and methods

2.1. Study Site

The study focused mangrove vegetation at the research stations in the villlages of Pasar Banggi, Tireman, and Kabongan Lor, as shown in Figure 1. The approximate geographic coordinates of these stations are presented in Table 1.

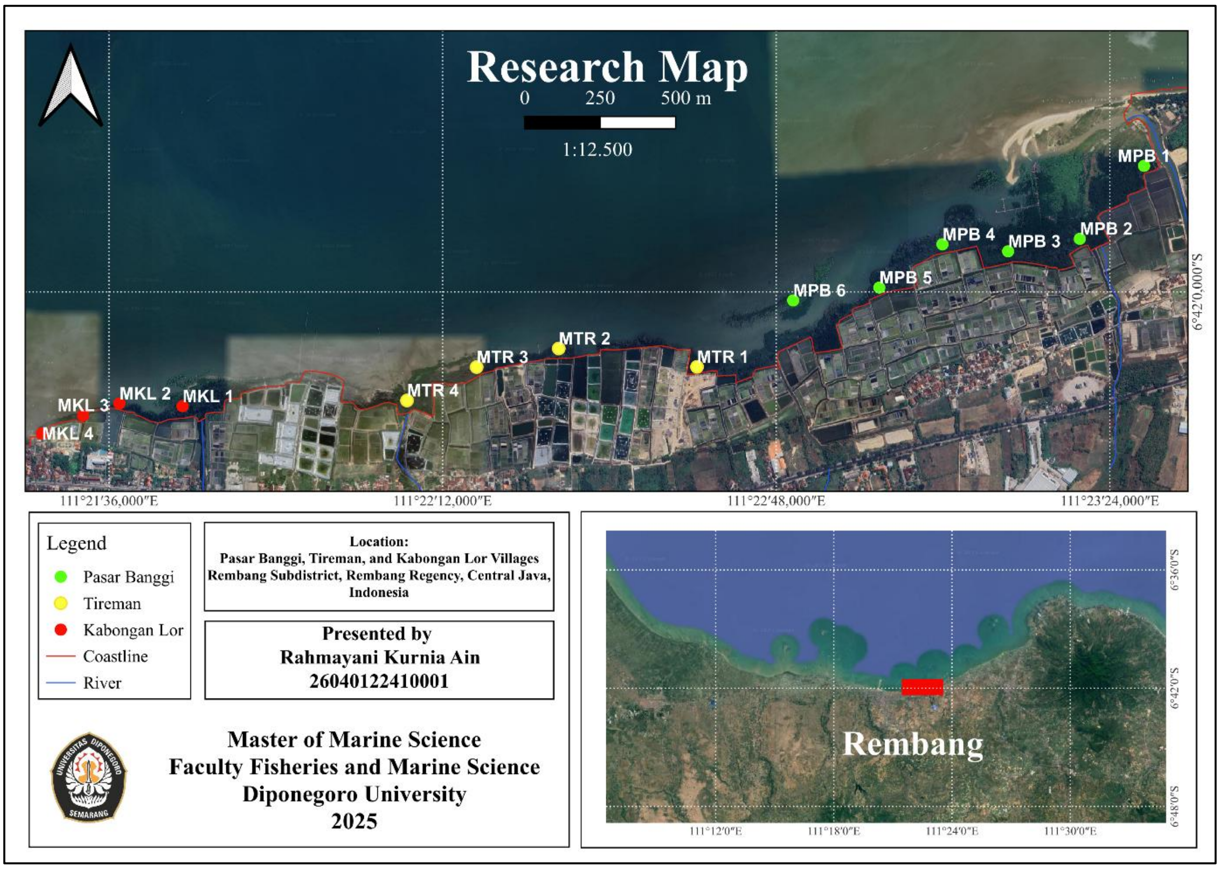

Figure 1. Research Location Map

2.2 NDVI

The distribution of mangrove canopy cover was calculated using the NDVI (Normalized Difference Vegetation Index) method. The NDVI Imagery was derived from Sentinel-2A satellite data acquired on 8 September 2024 from the Copernicus Open Access Hub in September 2024. The selected imagery had less than 5% cloud cover and a spatial resolution of 10 meters. Sentinel-2A was chosen because it provides the red band (Band 4) and Near Infrared (NIR) band (Band 8), which are required to calculate NDVI (Romadoni *et al*., 2023). Satellite image processing was conducted using ESA SNAP and QGIS 3.40 software. The downloaded Sentinel-2A imagery was processed using ESA SNAP software with the Sen2Cor module to perform atmospheric correction. This process converts top of atmosphere (TOA) reflectance into bottom of atmosphere (BOA) reflectance by accounting for atmospheric effects through a physical radiative transfer model. The corrected imagery was then exported in GeoTIFF format for further processing in QGIS (Rahmadi *et al*., 2021). Band composites were generated to enhance the visual distinction of mangrove vegetation. A combination of Band 8 (Near Infrared) and Band 4 (Red) was applied to highlight mangrove features. This helps in identifying mangrove and non-mangrove areas by observing the colour differences displayed.

Table 1. Geographic Coordinates of Research Stations in Rembang Subdistrict

No.	Station	Latitude (X)	Longitude (Y)
1.	MPB 1	6°41'46.40"S	111°23'27.67"E
2.	MPB 2	6°41'54.27"S	111°23'20.74"E
3.	MPB 3	6°41'55.62"S	111°23'13.00"E
4.	MPB 4	6°41'54.87"S	111°23'5.92"E
5.	MPB 5	6°41'59.53"S	111°22'59.11"E
6.	MPB 6	6°42'0.91"S	111°22'49.81"E
7.	MTR 1	6°42'8.08"S	111°22'39.44"E
8.	MTR 2	6°42'6.10"S	111°22'24.52"E
9.	MTR 3	6°42'8.11"S	111°22'15.66"E
10.	MTR 4	6°42'11.71"S	111°22'8.15"E
11.	MKL 1	6°42'12.32"S	111°21'43.94"E
12.	MKL 2	6°42'12.03"S	111°21'37.13"E
13.	MKL 3	6°42'13.31"S	111°21'33.22"E
14.	MKL 4	6°42'15.25"S	111°21'28.77"E

Next, image classification was performed to group homogeneous objects by assigning pixels into specific classes based on similarities in their digital values. Image classification also aims to distinguish mangrove vegetation from other land cover types. This process was carried out through visual interpretation of the imagery based on differences in colour, tone, texture, association, and patterns from the band composite results (Hayati *et al.*, 2022). Mangrove vegetation density was classified using an unsupervised clustering approach based on NDVI values. A pseudocolor scheme was applied to group NDVI ranges into three categories (dense, moderate, and sparse vegetation). This approach minimizes subjectivity compared to purely visual interpretation and allows clearer differentiation of vegetation cover. The condition of the mangrove vegetation was assessed using the NDVI, which focuses on mangrove canopy. The method for determining mangrove vegetation density values uses the ratio between the near infrared and red channels with the following formula (Damsir *et al*., 2023).

$$NDVI = (NIR – Red) / (NIR + Red)$$

Explanation:
NIR : *Band near infrared*
RED: *Band* red

The NDVI results were used to indicate the density level of mangroves at the research sites, with validation from field survey results to improve the accuracy of the NDVI output (Hanan *et al*., 2020). Field validation was conducted by collecting 14 coordinate points using handheld GPS. The sampling technique followed a purposive approach to ensure that the selected points represented the variability of mangrove and non mangrove areas within the study sites. These ground truth points were subsequently compared with the classification results and cross checked against an existing mangrove shapefile derived from field digitization. The procedure allowed for verification of the classification consistency with actual conditions in the field. Several studies have shown that NDVI values from Sentinel-2A are strongly correlated with mangrove density (r >0,75), making it an effective method for spatial monitoring of mangrove vegetation (Kawamuna *et al*., 2017).

The condition of mangrove vegetation was then classified based on the guidelines issued by the Ministry (2005). These guidelines define mangrove vegetation criteria based on canopy cover and mangrove density using NDVI values. The cirteria for mangrove vegetation condition are further presented in Table 2.

Table 2. Vegetation Index Values, Canopy Cover Levels, and Mangrove Status

No.	NDVI Value	Canopy Cover (%)	Density Level	Mangrove Status
1.	≥ 0,43 – 1,00	≥ 75	Dense	Good
2.	≥ 0,33 - < 0,42	≥ 50 - < 75	Moderate	Good
3.	0 - < 0,32	< 50	Sparse	Damage

(Source: Ministry of Forestry, 2005)

3. Results

The results of mangrove canopy cover distribution derived from Sentinel-2A imagery processing show a diversity of canopy cover across the three villages, as further presented in Figures 2, 3, and 4. The NDVI values in Pasar Banggi, Tireman, and Kabongan Lor Villages range from 0.2 to 0.63. Figure 2 shows that the mangrove density at MPB1 falls into the moderate category, as indicated by the dominant yellow colour. Dense mangrove areas, represented by green, are only found in the central part of MPB1. MPB2 and MPB3 have high mangrove density, indicated by the dominant green colour. MPB4 and MPB5 are classified as having moderate mangrove conditions, marked by the yellow colour. MPB6 falls under the dense mangrove category, dominated by green. In the NDVI results, non-vegetation areas are displayed in grey, as observed in the southern part of Pasar Banggi Village. The figure also shows that Pasar Banggi Village has two rivers that serve as freshwater sources for the mangrove area.

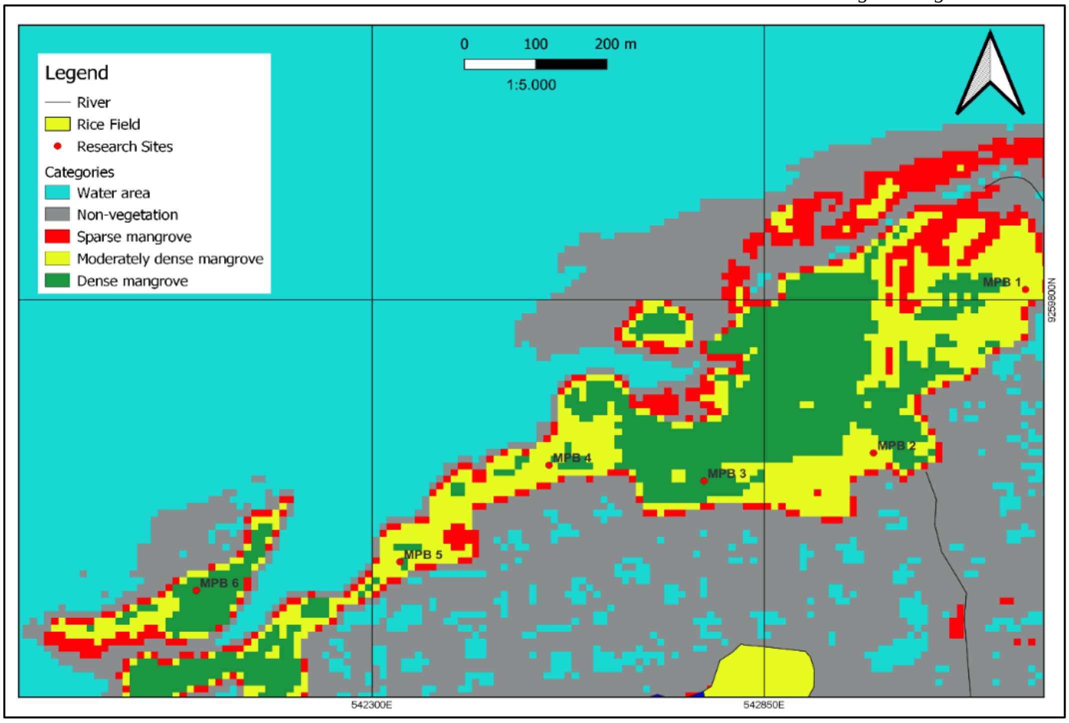

Figure 2. Mangrove Canopy Cover Distribution in Pasar Banggi Village

Figure 3 shows that mangrove density in Tireman Village varies from sparse to dense. Tireman Village directly borders salt pond areas to the south. The figure indicates that the mangroves in Tireman Village do not have a wide mangrove belt. MTR1 is located at the eastern end, bordering Pasar Banggi Village. This station is also adjacent to wastewater discharge from salt ponds. MTR1 is dominated by dense mangroves, indicated by green, with moderate mangroves (yellow) near the area bordering the salt pond discharge. MTR2 is dominated by moderately dense mangroves, shown in yellow. MTR3 exhibited the lowest NDVI values, indicating sparse mangrove cover. MTR4 has dense mangroves in the central part, marked in green, and is surrounded by moderately dense mangroves, shown in yellow. The river in Tireman Village flows into the research station at MTR4.

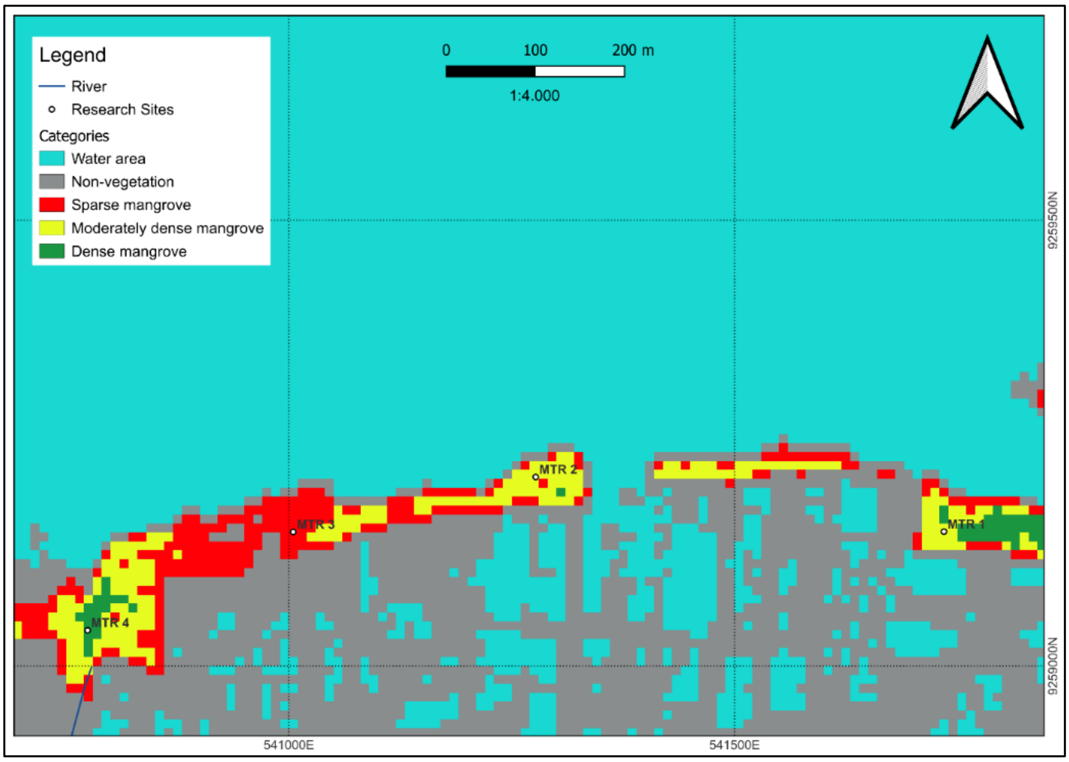

Figure 3. Mangrove Canopy Cover Distribution in Tireman Village

Figure 4 shows that the mangrove density in Kabongan Lor Village is dominated by moderately dense to dense mangroves. MKL1 is located at the easternmost part of Kabongan Lor Village and is marked in green, indicating dense mangrove cover. MKL1 is the research station with the thickest mangrove belt when measured from the coastline to the land boundary. MKL2 contains both moderately dense and dense mangroves, indicated by yellow and green colours. MKL3 is predominantly covered by moderately dense mangroves, as is MKL4, which is entirely categorized as moderate, marked in yellow. MKL1 is the only research station surrounded by a river mouth. The southern part of MKL1 and MKL2 consists of non-vegetated areas in the form of aquaculture ponds, while the southern part of MKL3 and MKL4 consists of non-vegetated areas in the form of buildings.

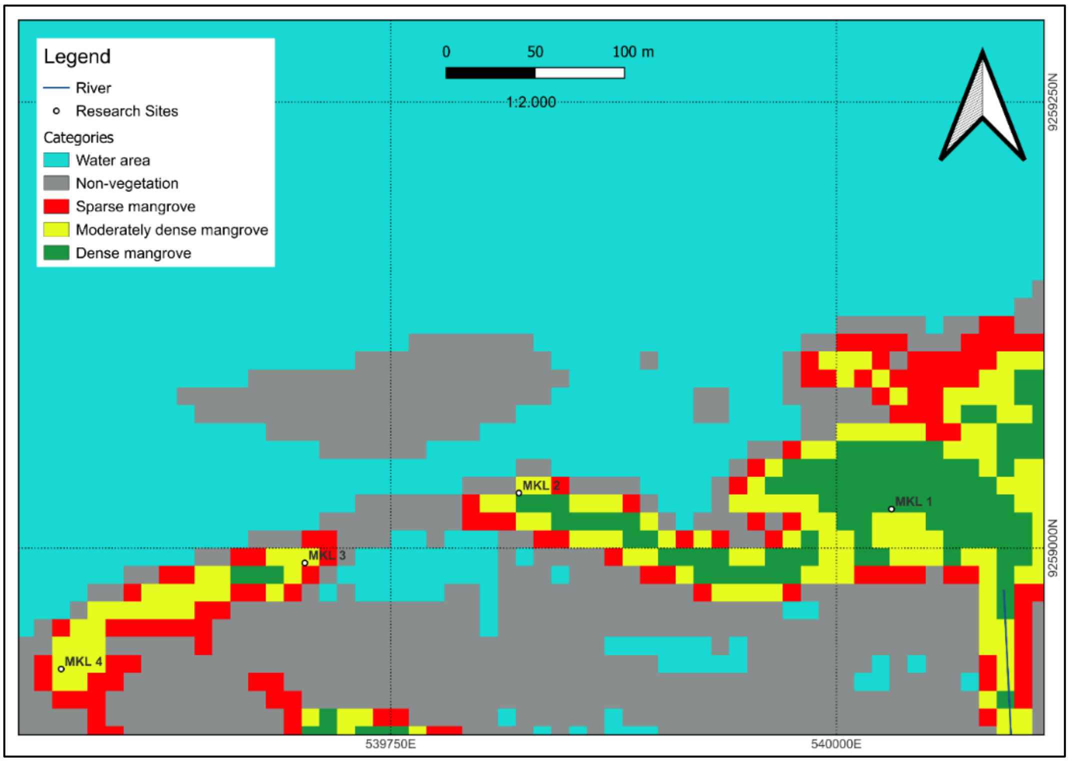

Figure 4. Mangrove Canopy Cover Distribution in Kabongan Lor Village

The results of mangrove vegetation condition at each research station are further presented in Table 3. Table 3 shows the mangrove vegetation condition at each research station. Almost The majority of stations were classified as being in good condition with NDVI values ranging drom 0.33 to 0.66. While, only two stations, MTR3 (NDVI <0.33) and MKL4 (NDVI 0.20 – 0.30), were categorized as damaged due to low canopy cover (<50%). Dense mangroves (NDVI ≈ 0.66; canopy cover > 75%) were identified only at MPB3 and MPB6, whereas moderately to densely vegetated mangroves were found at MPB2, MTR1, and MKL1. Stations MPB1, MPB4, MPB5, MTR2, and MTR4 exhibited moderate density (NDVI 0.33 – 0.42; canopy cover 50 – 75%), while MKL3 showed sparse to moderate density (NDVI 0.20 – 0.40). The lowest vegetation condition, sparse mangrove was recorded at MTR3 and MKL4.

Table 3. Mangrove Vegetation Status in Pasar Banggi, Tireman, and Kabongan Lor Villages

No.	Research Stations	NDVI Value	Canopy Cover (%)	Density Level	Mangrove Status
1.	MPB1	0,33 – 0,42	50 – 75	Moderate	Good
2.	MPB2	0,42 – 0,6	>75	Moderate - Dense	Good
3.	MPB3	0,6	>75	Dense	Good
4.	MPB4	0,33 – 0,42	50 – 75	Moderate	Good
5.	MPB5	0,33 – 0,42	50 – 75	Moderate	Good
6.	MPB6	0,6	>75	Dense	Good
7.	MTR1	0,42 – 0,6	>75	Moderate - Dense	Good
8.	MTR2	0,33 – 0,42	50 – 75	Moderate	Good
9.	MTR3	<0,33	<50	Sparse	Damage
10.	MTR4	0,33 – 0,5	50 – 75	Moderate	Good
11.	MKL1	0,42 – 0,6	>75	Moderate - Dense	Good
12.	MKL2	0,33 – 0,42	50 – 75	Moderate	Good
13.	MKL3	0,2 – 0,4	50	Sparse - Moderate	Good
14.	MKL4	0,2 – 0,3	<50	Sparse	Damage

4. Discussion

The NDVI analysis in Rembang Subdistrict provides a spatial overview of mangrove vegetation density variation across the villages. NDVI values in Pasar Banggi Village range from 0,44 to 0,68, indicating dense to very dense mangrove vegetation. These findings reflect a well distributed and healthy mangrove cover, supported by NDVI values of 0.33 – 0.60, which are classified as moderate to dense vegetation (Purwanto and Eviliyanto, 2021). This condition aligns with high ecological and social land suitability, suggesting that Pasar Banggi holds the most favorable position to support sustainable mangrove rehabilitation. The highest NDVI value reaching 0,68 (MPB6), further confirms the suitability of this area. These results align with a study by Joandani *et al*. (2019), which reported a 75% mangrove density in Pasar Banggi, categorized as good, which is consistent with the current NDVI findings.

In contrast, Tireman Village shows lower NDVI values, ranging from 0,23 to 0,39, placing it in the moderate vegetation category. At observation stations MTR2 and MTR4, NDVI values approach the lower limit of this class, indicating that portions of the mangrove vegetation remain sparse. While land suitability assessments suggest potential for rehabilitation, NDVI results reveal that vegetation growth has not reached its full potential. These results highlight the need for continuous monitoring and adaptive management to address environmental stressor, including abrasion and wastewater from nearby salt ponds.

Kabongan Lor Village shows the lowest NDVI values, ranging from 0,12 to 0,21, which fall into the sparse to very sparse vegetation category. All observation points (MKL1 – MKL4) show very low vegetation density, approaching the lower threshold for green vegetation existence. These results are consistent with field conditions that show minimal mangrove cover and dominance of fishponds or open land. Substrate unsuitability, high abrasion, and other anthropogenic pressures are the main factors contributing to the low NDVI values. These identifications were based on field observations during site visits and are also supported by previous studies on coastal vulnerability in Rembang. Arini *et al.* (2014) demonstrated that shoreline segments in Rembang range from low to very high vulnerability, with mangrove degradation strongly linked to anthropogenic shoreline modifications. Similarly, Huda *et al.* (2019) emphasized that land use and human activities substantially influence coastal resilience. Under such conditions, this area is not yet suitable for rehabilitation without major technical interventions such as wave barrier structures or substrate engineering.

Compared with existing literature, the NDVI value of 0,68 in Pasar Banggi is similar to the findings of Singgalen (2023), who stated that values above 0.6 indicate a healthy and dense mangrove area. Meanwhile, NDVI values in Tireman and Kabongan Lor (0,23 – 0,6) resemble those found by Anwar *et al*. (2023), who observed that mangroves under pressure from abrasion and pollution tend to show NDVI values below 0,3. This comparison reinforces the conclusion that NDVI is a reliable tool for assessing vegetation quality and the potential success of rehabilitation. Additionally, NDVI values can provide insights into the history of ecological interventions in an area, including the duration and effectiveness of rehabilitation efforts. In Pasar Banggi, the NDVI trends suggest a positive response to rehabilitation activities, indicating significant vegetation recovery.

However, the success of the efforts is closely linked to land suitability and hydrological conditions. Studies have shown that suitable land elevation, salinity levels, and hydrological connectivity are crucial for mangrove establishment and growth. For instance, research in Muara Gembong, Bekasi, demonstrated that areas with optimal salinity and substrate conditions were more conductive to mangrove rehabilitation. Similarly, Van Huijgevoort *et al.* (2016) emphasized that disregarding hydrological conditions can lead to restoration failures, as hydrological suitability directly influences mangrove species distribution and survival. Multiple ecological and anthropogenic factors influence NDVI patterns. Variation in tidal inundation frequency, substrate suitability, sediment trapping capacity, and canopy regeneration post rehabilitation directly affect vegetation density. Species composition and leaf area index also play a role by altering spectral reflectance and NDVI values. Furthermore, social and regularoty factors, such as local conservation initiatives and community engagement, contribute to observed NDVI trends

NDVI values also reflect the real outcomes of mangrove rehabilitation efforts. In Pasar Banggi, the presence of local conservation regulations, social support, and appropriate rehabilitation methods have contributed to the continuous increase in NDVI values. Conversely, in Tireman and Kabongan Lor, rehabilitation efforts have resulted in sparse vegetation. This condition appears to be influenced by high abrasion, as reported by Arfianto (2019), who noted that inappropriate development in coastal buffer zones can exacerbate coastal erosion and reduce vegetation establishment, and corroborated by local knowledge obtained from community informants as well as direct observations of domestic waste during field surveys. As stated by I'zzudiin *et al*. (2025), stagnation or decline in NDVI after rehabilitation may indicate program failure or ongoing environmental challenges. Therefore, NDVI should be used as a long-term evaluative indicator to ensure the success of vegetation based rehabilitation programs.

In conclusion, the NDVI analysis across the three villages in Rembang Subdistrict shows significant differences in vegetation density. Pasar Banggi, with the highest NDVI values, reflects an area that has achieved ecological success, while Tireman and Kabongan Lor are still in recovery phases or even in a state of degradation. This shows that NDVI can be used both for spatial mapping and for monitoring rehabilitation outcomes. The NDVI values in this study align with findings from other studies along the northern coast of Java, supporting its application in strategic mangrove rehabilitation planning. By integrating NDVI, land suitability data, and field observations, mangrove management in Rembang can be more evidence based.

Based on the obtained mangrove density distribution, the mangrove damage status at each research station can be determined. In Pasar Banggi Village, most research stations fall into the healthy category, where mangrove canopy density is in the moderate to dense range. Tireman Village has mangrove damage status categorized as mostly damaged to moderate, due to thin mangrove belts and sparse to moderate canopy density. In Kabongan Lor, mangrove damage status ranges from healthy to moderate at station MKL1, and from damaged to moderate at the other stations. These classifications refer to the 2005 Guidelines for Mangrove Critical Land Inventory and Identification.

5. Conclusions

Based on the distribution of mangrove canopy cover, the villages of Pasar Banggi, Tireman, and Kabongan Lor generally suggests that targeted rehabilitation efforts can lead to measurable improvements in vegetation cover, as reflected in NDVI trends. However, certain observation stations indicate degraded conditions, highlighting the need for further investigation into specific factors affecting mangrove recovery, such as hydrological disruption, land conversion, and domestic waste pollution observed in the study areas. particularly in terms of land suitability and hydrological systems. Such additional analysis is essential to complement existing data and support the strategic development of mangrove areas in Rembang Subdistrict, by integrating NDVI monitoring into local management policies and prioritizing rehabilitation in degraded sites.

Ethics approval
No permits were required.

Data availability statement
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Author contributions
RKA is responsible for data curation, conceptualization, project administration, funding acquisition, writing – review & editing the original draft. RP and S are contributed to investigation, resource acquisition, methodology, and formal analysis.

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Declaration of competing Interest
None

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