p-ISSN 2460-0768 e-ISSN 2597-6044
GeoEco, Vol. 11, No 2. July 2025 Page. 501 - 518
https://doi.org/10.20961/ge.v11i2.86711
https://jurnal.uns.ac.id/GeoEco/article/view/86711

ANALYSIS OF NDVI, NDWI, AND SAVI TRANSFORMATIONS FOR IDENTIFICATION OF MANGROVE DENSITY IN BENGKULU

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ARTICLE INFO

Article History
Received : 19/05/2024
Revised : 12/06/2025
Accepted : 07/07/2025

Citation:
Komura, A.I.R., Sumarmi., and Bachri, S., (2025) Analysis of NDVI, NDWI, and SAVI Transformations for Identification of Mangrove Density in Bengkulu. GeoEco. Vol. 11, No. 2.

ABSTRACT

This study was conducted in the mangrove forest area of Bengkulu City, Indonesia, which is rich in ecosystem diversity and has a long coastline. By utilising remote sensing technology, this study aimed to provide accurate information on the condition of mangrove forests and their role in the local ecosystem. Sentinel image analysis using NDVI, SAVI, and NDWI vegetation indices showed that NDVI was dominated by high density with values between 0.35 and 1, covering an area of 674.19 hectares. In the SAVI analysis, an extremely high density class with values 1.22 to 1.38 covered an area of 457.82 hectares. Conversely, NDWI indicated a low-density class with values between 0.17 and 0.27, covering an area of 457.82 hectares. Accuracy tests conducted with 30 samples showed an accuracy level of 83.33%. It is hoped that this study's results can significantly contribute to the understanding and management of mangrove ecosystems in Bengkulu City.

Keywords: *Mangrove; NDVI; NDWI; SAVI; Sentinel*

INTRODUCTION

Mangrove forests worldwide cover an area of approximately 15 million hectares and are spread across 123 countries, including Indonesia, which has around 3.6 million hectares, or about 25% of the world's total mangrove area. However, this ecosystem is experiencing a significant decline due to poor management and rapid development in the socio-economic sector (Menlhk 2021). Mangroves typically grow in estuaries, intertidal zones, and coastal areas (Mukti, Hudjimartsu, and Hermawan 2023). Mangrove plants play a crucial role in maintaining marine habitats. Given Indonesia's geographical vulnerability to sea waves and coastal erosion, mangrove growth is greatly aided (Lestari et al. 2015). With over 13,466 islands and a coastline of approximately 81,000 kilometres, Indonesia has significant potential for mangrove ecosystem development. Unsurprisingly, one-third of the world's mangroves are found in this region.

The situation in Bengkulu is increasingly dire. The total area of mangrove forests is approximately 247.61 hectares, with 118.14 hectares designated as the TWA Pantai Panjang – Baai Island area. The

Mangrove Forest in Bengkulu Bay faces four leading causes of degradation: coastal erosion, conversion of mangroves into tourist attractions, mangrove mining, and illegal logging by irresponsible parties (Li et al. 2024; Senoaji and Hidayat 2017). If not addressed promptly, these issues could lead to disasters caused by seawater erosion.

The condition of the mangrove forest in Bengkulu is already concerning, covering an area of approximately 247.61 hectares, with 118.14 hectares of it located within the TWA Pantai Panjang – Pulau Baai area. The mangrove area in Bengkulu Bay faces four main issues: coastal erosion, conversion of mangroves into tourist areas, mining activities, and illegal logging. One of the leading causes of mangrove damage is human activities that alter their vegetation composition (Zuhdi and Pribadi 2024). Mangrove damage can trigger disasters if effective protection measures are not implemented, such as erosion caused by sea waves (Ardhi Prasetyo Utomo et al. 2024)

Changes in mangrove vegetation density in the Bengkulu region, particularly on Pulau Baai near Red Letter, indicate that erosion remains mild, with access still possible in 2023. However, erosion has now spread to Red Letter, and access is only possible during low tide. This underscores the importance of mangrove vegetation density in maintaining ecosystem sustainability and community well-being in Bengkulu City (Prasetyo, Valentino, and Hambali 2024).

Similar research using Sentinel satellites has been conducted previously. One study successfully identified areas requiring protection for mangrove forests in Lampung Province. This research aimed to determine mangrove ecosystem density using the NDVI, NDWI, and SAVI to identify mangrove types and density. Another study has been conducted to map mangroves in Bengkulu City (Simarmata et al. 2021). This study considered the NDVI and conducted accuracy tests in Bengkulu City based on Sentinel 2 satellite imagery, successfully dividing mangrove areas into three categories: sparse, moderate, and dense (Kurniawan, Wilopo, and Bakhtiar 2023).

This study proposes a new method combining three vegetation indices, NDVI, NDWI, and SAVI, to distribute mangrove density in Bengkulu City. This combination has never been applied before, especially in Pantai Panjang and Pulau Baai TWA, which are facing abrasion problems. This study will be the first spatial data source that combines the three indices for mangroves in Bengkulu, which can support evidence-based conservation policies. The resulting data is crucial to reducing the risk of ecological disasters caused by abrasion and human activities, such as land use change and mining.

To support mangrove forest monitoring and management efforts, advances in science have encouraged the use of geographic information systems (GIS) technology, which plays a crucial role in collecting, storing, and analysing spatial data (Putri, Sukmono, and Sudarsono 2018). Technologies such as GPS, remote sensing, and total stations make it easier to record digital locations quickly and efficiently (Fauzi 2020). With increasing storage capacity, data transmission speed, and high processing capabilities, spatial data has become an increasingly important element in the development of information technology (Rahmadana 2023).

To address various existing issues, this study was conducted to identify the types and density of mangrove vegetation. The study used various indices, such as the Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), and Soil Adjusted Vegetation Index (SAVI), to improve Accuracy in identifying mangrove species and density.

MATERIALS AND METHODS

At this stage, researchers collect various data needed for research purposes. The data needed includes Sentinel-2 satellite imagery. To ensure the research is conducted effectively, this study also requires various supporting tools and materials, including additional data such as GPS, ArcGIS 10.8 software, and Sentinel imagery for May 2023, captured using Band 4 (Red), Band 3 (Green), Band 8 (NIR), and Band 11 (SWIR1).

The first stage of this research was to determine the methods to be used, conduct a literature review, and collect data. During the literature review stage, references were sought from previous studies related to the research being conducted. Data processing was carried out using ArcGIS 10.8 by classifying each item that had been created previously. After obtaining the classification results, field data validation tests were conducted, followed by accuracy tests. Further details can be seen in the research flowchart described in **Figure 1**.

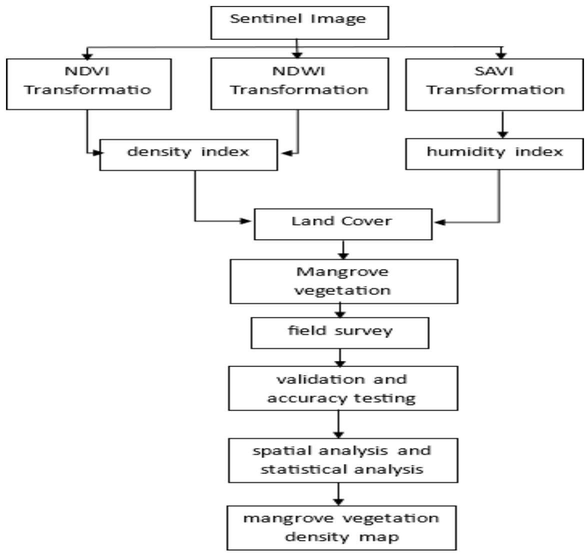

Figure 1. Research flow diagram

1. Normalized Difference Vegetation Index (NDVI)

The Normalised Difference Vegetation Index (NDVI) is an image processing method for measuring the greenness of vegetation. It can show various related parameters and can be used to classify vegetation types. This index provides a numerical value between -1 and 1, reflecting the density of vegetation coverage. A value close to 1 indicates dense vegetation, while below zero usually indicates water or clouds (Kurniawan et al. 2023; Sorkhabi 2024; Sumarmi et al. 2022).

Algorithms in remote sensing applications measure vegetation greenness levels using infrared waves (Atmojo et al. 2024; Febriansyah et al. 2018).

Vegetation index analysis using the NDVI method aims to measure mangrove canopy density levels. The formulated index value (NDVI) method is formulated as stated in Equation (1) (Bachri et al. 2021; Cahyono, Rahagian, and Nugroho 2023; Kurniawan et al. 2023; Li et al. 2024; Putri et al. 2018; Sapkota et al. 2025).

$$NDVI = \left(\frac{Band\ NIR - Band\ Red}{Band\ NIR + Band\ Red}\right) \quad (1)$$

Informati

on:

NDVI = Normalized Difference Vegetation Index
NIR = Band near infrared (Band 8)
RED = Band Red (Band 4)

2. Normalized Difference Water Index (NDWI)

Remote sensing data with a high spatial resolution of 10 m was taken from Sentinel-2 imagery, and the NDWI index was used to assess the swamps' hydrological conditions and analyse the relationship between the conditions of the area.

This index is specifically designed to describe open water features and enhance their visibility in digital images generated from remote sensing. In this analysis, the Green band and NIR band from Sentinel-2 image data were used. The NDWI method is formulated as stated in Equation (2) (Teng et al. 2021) as follows:

$$\text{NDWI} = \left(\frac{Band\ Green - Band\ NIR}{Band\ Green + Band\ NIR}\right) \quad (2)$$

Information:

NDWI = Normalized Difference Water Index
GREEN = Near Infrared Band
NIR = Band near infrared

3. SAVI (*Soil Adjusted Vegetation Index)*

The Soil-Adjusted Vegetation Index (SAVI) is an algorithm developed from NDVI to reduce the influence of soil background on canopy brightness (Simarmata et al., 2021). Additionally, SAVI time series often contain various sources of interference from factors such as atmospheric disturbance, cloud cover, and hill shadows. This results in the initial SAVI time series showing more noise and wider gaps (Sun et al. 2024).

The SAVI method uses band 3 (Green) and band 11 (SWIR1), with the SAVI formula shown in Equation (3). (Deng et al. 2023; Eramudadi and Rokhmana 2024; González-Gómez et al. 2022):

$$\text{SAVI} = (1{,}5)\ \text{X}\ \frac{(\text{Band Green} - \text{Band SWIR1})}{(\text{Band Green} + \text{Band SWIR1} + 0{,}5)} \quad (3)$$

Information:

SAVI = Soil-Adjusted Vegetation Index
GREEN = Green Band
SWIR1 = Short-Wave Infrared Band
L = Soil Background

Brightness (0.5)

4. Confession Matrix

   Another solution to consider is selecting different probability thresholds by utilising confusion matrices and various accuracy-based classification measures developed to aid interpretation (Phillips et al. 2024).

Used to compare actual values with predicted values in classification, where rows represent actual classes and columns represent predicted classes. Each entry (k,k) lists the data points from class j predicted as class i (Düntsch and Gediga 2020). The Confession Matrix is shown in **Table 1**.

Table 1. Confession Matrix

	True value				**Sum**
	Y_1	**…**	Y_j	Y_k	
Y_1	…	…	…	…	$Y_1 n$
…	…	…	…	…	…
Y_j	…	…	…	…	$Y_j n$
…	…	…	…	…	…
Y_k	…	…	…	…	$Y_k n$

RESULTS AND DISCUSSION

1. Normalized Difference Vegetation Index (NDVI)

Based on the Sentinel-2A satellite image analysis results, the density of mangrove vegetation in the coastal area of Bengkulu City was determined using the Normalised Difference Vegetation Index (NDVI) transformation. The results of the analysis presented in **Table 2** show that the NDVI value in the coastal area of Bengkulu City shows a striking difference, with a range between -0.99 and 1, which reflects various conditions of mangrove vegetation.

Table 2. Mangrove Density Criteria Based On NDVI

Number	**NDVI Value Classification**	**Density Range**	**Area (hectares)**
1	-0,99 - -0,03	Extremely Low	0,92
2	-0.03 – 0.15	Low	69,79
3	0.15 – 0.25	currently	65,58
4	0.25 – 0.35	High	125,72
5	0.35 – 1	Extremely High	674,19

Source: Processing results (2023)

p-ISSN 2460-0768 e-ISSN 2597-6044
https://doi.org/10.20961/ge.v11i2.86711

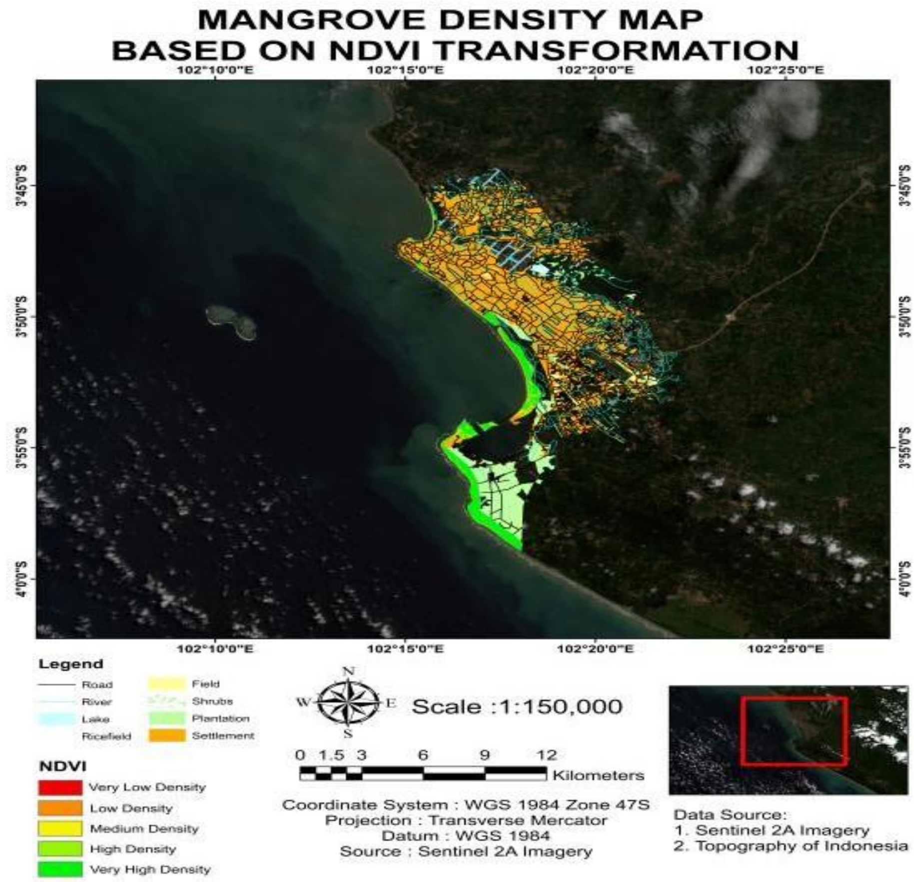

Figure 2. Map of mangrove vegetation density as a result of the NDVI index

Specifically, the "extremely high" density class (NDVI between 0.35 and 1) dominates the Bengkulu City area, covering an area of 674.19 hectares. This section is seen in a striking dark green colour on the vegetation density map (**Figure 2**), indicating the presence of an extremely dense and productive mangrove ecosystem. This high density indicates that the vegetation is in optimal condition to absorb carbon dioxide and provide habitat for various species.

This finding is in line with many previous studies that show the effectiveness of NDVI in photographing and assessing the density of mangrove vegetation, including research (Kurniawan et al. 2023), which also utilised Sentinel-2 imagery in the Pantai Panjang TWA, Bengkulu City. Theoretically, the ability of NDVI to assess the level of greenness of vegetation is based on the spectral properties of chlorophyll, which absorbs red light and reflects near-infrared light; the more chlorophyll, the higher the NDVI value (Atmojo et al. 2024; Bachri et al. 2024; Sumarmi, Purwanto, and

Bachri 2021). Therefore, the high NDVI value in most areas of Bengkulu indicates the abundance of biomass and active physiological conditions of mangroves.

The spatial distribution of high mangrove density in Bengkulu City, as explained by NDVI, can be explained by several reasons. First, the extremely supportive natural environmental conditions in the coastal areas of Bengkulu, especially around the Pantai Panjang and Pulau Baai TWA, with geographical characteristics such as tidal areas and river estuaries that provide fresh water supplies and sediments rich in nutrients, are extremely supportive of mangrove growth (Mukti et al. 2023). Second, the existence of a location designated as the Pantai Panjang - Pulau Baai Nature Tourism Park (TWA) indicates that there are conservation and management efforts that help maintain mangrove density.

However, it should be noted that even though there is a high density, the existence of "low" (69.79 hectares) and "currently" (65.58 hectares) density classes on the NDVI map indicates that there are areas that are experiencing degradation. This degradation may be caused by human activities such as changing mangrove forests into tourism areas, mining, illegal logging (Zuhdi and Pribadi 2024), and coastal erosion. This spatial mapping makes it possible to identify critical areas requiring further conservation or rehabilitation.

Overall, the NDVI analysis provides a clear picture of the health and density of mangrove vegetation in Bengkulu City, highlighting fertile areas and identifying potential areas threatened with degradation, which is extremely important for planning sustainable mangrove ecosystem management.

2. Soil Adjusted Vegetation Index (SAVI)

Image processing using the Land-Adjusted Vegetation Index (SAVI) was also carried out to evaluate the density of mangrove vegetation on the coast of Bengkulu City. The results of this analysis are presented in **Table 3** and **Figure 3**.

Table 3. Mangrove Density Criteria Based On SAVI

Number	SAVI Value Classification	Density Range	Area (hectares)
1	0.87 – 1.03	Extremely Low	209,84
2	1.03 – 1.09	Low	374,63
3	1.09 – 1.16	Currently	230,67
4	1.16 – 1.22	High	106,83
5	1.22 – 1.33	Extremely High	12,24

Source: Processing results (2023)

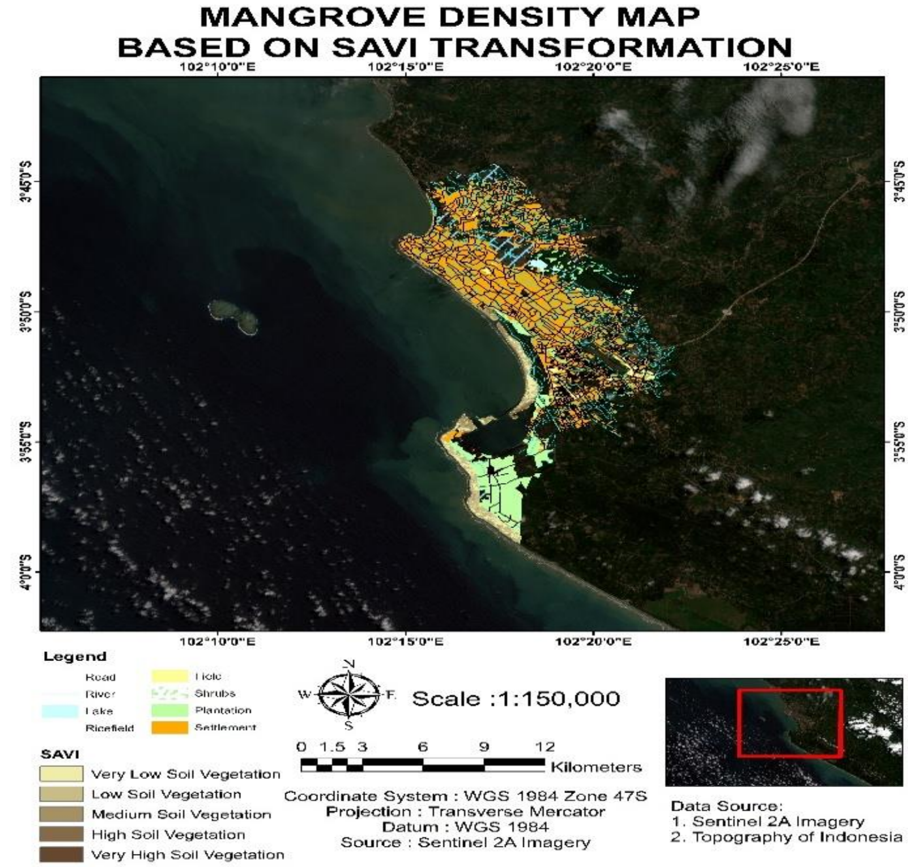

Figure 3. Map of mangrove vegetation density from the SAVI index

The SAVI algorithm is derived from NDVI with the primary objective of reducing the impact of the ground background on the brightness of the canopy, as well as reducing atmospheric interference and shadows from hills (Deng et al. 2023; Eramudadi and Rokhmana 2024). This makes SAVI more appropriate for use in areas with vegetation cover that is not completely dense or where open land can affect the results of the vegetation index.

From the analysis of Sentinel-2A imagery, it can be seen that the coast of Bengkulu City is mostly covered by mangrove vegetation with a high density level. This can be seen clearly on the map (Figure 3), where the striking brown indicates significant vegetation density.

Specifically, in the SAVI analysis, the density class is classified as "extremely high" with a value between 1.22 and 1.33, covering an area of 374.63 hectares. The SAVI index value provides important information for understanding the area's condition and distribution of mangrove forests. This finding is in line with other studies that use SAVI to evaluate vegetation density in various ecosystems, showing that SAVI is effective in identifying areas with extremely high mangrove density (González-Gómez et al. 2022; Prasetyo et al. 2024). A high SAVI value (close to 1.33) indicates higher quality and dense vegetation (Zhen et al. 2023).

The spatial distribution of mangrove density based on SAVI shows a high concentration in the same areas identified by NDVI, confirming the presence of a healthy and dense mangrove ecosystem. Areas with extremely high density (1.22-1.33) are likely to be core zones for conservation or locations that naturally have soil and hydrological conditions that support mangrove growth.

Meanwhile, areas with low or extremely low density on SAVI (0.87-1.09) may indicate areas that have experienced degradation due to natural factors such as abrasion on the island of Baai near the red letter. The use of SAVI in this analysis provides additional validation of the NDVI results, especially in locations where significant soil influences are possible, thereby increasing the reliability of mangrove density assessments.

3. Normalized Difference Water Index (NDWI)

Mangrove vegetation density was also analysed using the Normalized Difference Water Index (NDWI). The NDWI value ranges from -1 to +1, where positive values indicate the presence of water or high humidity, while negative values indicate dry areas or no water sources. The results can be seen in **Table 4** and **Figure 4.**

Table 4. Mangrove Density Criteria Based On NDWI

Number	NDWI Value Classification	Density Range	Area (hectares)
1	-0.99 – 0.1	No Water	5,57
2	0.1 – 0.17	Extremely Low	178,77
3	0.17 – 0.27	Low	342,57
4	0.27 – 0.37	Currently	203,44
5	0.37 – 0.47	High	155,82
6	0.47 – 1	Extremely High	48,87

Source: Processing results (2023)

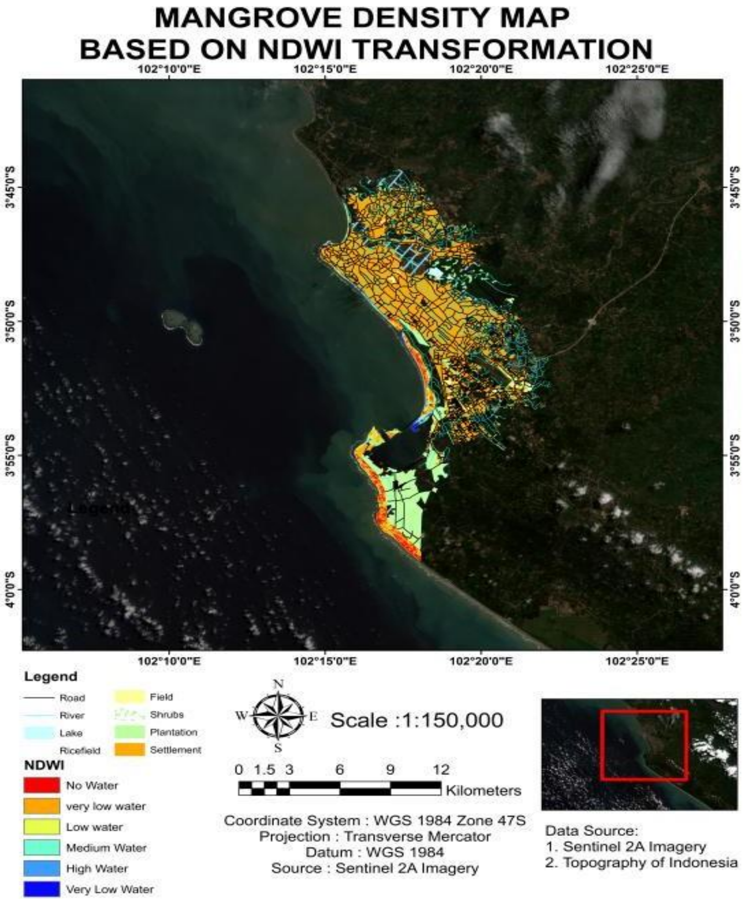

Figure 4. Map of mangrove vegetation density as a result of the NDWI index

NDWI is a tool created to explain the characteristics of open water and the hydrological conditions of an area, which are extremely important for ecosystems such as mangroves that are highly dependent on water availability (Cahyono et al. 2023; Teng et al. 2021).

From the analysis shown in **Figure 4**, it can be seen that the coast in Bengkulu City has variations in vegetation density that are influenced by humidity levels. The NDWI value in Bengkulu City ranges from 0.24 to 0.47. This range indicates moderate to high humidity, which generally supports

p-ISSN 2460-0768 e-ISSN 2597-6044
https://doi.org/10.20961/ge.v11i2.86711

vegetation growth.

However, the NDWI analysis also shows areas with low density with values between 0.17 and 0.27, covering an area of 457.82 hectares. This finding provides important information about the moisture status in the mangrove ecosystem, which is crucial for better management and conservation.

This study is in line with the results of (Tudorescu et al. 2024; Zheng, Tang, and Wang 2021), which indicate that NDWI, together with other indices, can provide important data on the condition and distribution of vegetation, especially those related to water availability. In the context of mangroves, NDWI can identify areas with low density, which poor moisture conditions may cause may cause. The distribution of NDWI shows that areas with low density (0.17-0.27) cover a fairly large area. This could indicate that although there are dense mangrove areas, some also experience drought or a lack of water supply, inhibiting their growth.

Various factors, such as changes in tidal patterns, reduced freshwater intrusion, or topographic changes due to human activities (such as infrastructure development that disrupts water flow), can affect the moisture level in the area. This knowledge is essential for designing successful conservation strategies, such as hydrological restoration or planting mangrove species that are more tolerant of dry conditions in identified coastal areas of Bengkulu City.

4. Confession Matrix

Accuracy testing was conducted using the Confusion Matrix, an important tool for evaluating model classification performance. In this study, accuracy measurements were conducted by utilising 30 sample points taken directly from the location to compare the mangrove density map classification results with actual field data. The results of the accuracy test can be found in **Table 4.**

The Confusion Matrix provides information on the number of correct and incorrect predictions for each category, as well as calculating the overall Accuracy of the model used.

Table 5. Mangrove Density Map Accuracy Test

Image Data	**Field Data**						
	No Vegetation	**Extremely Low**	**Low**	**Currently**	**High**	**Extremely High**	**User Accuracy (%)**
No Vegetation	5	0	0	0	0	0	100
Extremely Low	0	5	0	0	0	0	100
Low	0	1	3	1	0	0	60
Currently	0	0	0	5	0	0	100
High	0	0	2	0	3	0	60
Extremely High	0	0	0	0	1	4	80
Total	5	6	5	6	4	4	
Prodecer Accuracy (%)	100	83,33	60	83,33	75	100	
Overall Accuracy (%)	83,33						

Source: Researcher Analysis, 2023

Based on the analysis, the overall accuracy level obtained was 83.33%, indicating that the remote sensing method applied effectively recognised conditions in the field (Kurniawan et al. 2023). **Table 4** shows that all classifications, from "extremely low" to "extremely high", achieved 100% accuracy, meaning that the map classification results classified all sample points. This finding confirms that the classification model used could accurately recognise the condition of mangrove vegetation at the research location.

This high level of Accuracy is in line with previous studies that also used the Confusion Matrix to assess land cover classification results. For example, research (Putri et al. 2018) showed high Accuracy in classifying land cover using satellite imagery.

A Confusion Matrix provides an overall picture of Accuracy. It offers information on specific performance for each category, which is extremely helpful in understanding which aspects of the model may need to be improved. Therefore, the results of this accuracy measurement indicate that Sentinel-2A Imagery and the analysis method applied in this study are reliable for mapping and managing mangrove ecosystems in Bengkulu City.

Overall, using the Confusion Matrix in this study provides strong validation of the classification results and highlights the potential use of remote sensing technology in monitoring and managing natural resources, especially mangrove ecosystems, which are extremely important for environmental sustainability.

CONCLUSIONS

Analysis of mangrove forest density in the coastal area of Bengkulu using Sentinel-2 imagery and three vegetation indices (NDVI, NDWI, and SAVI) showed a dominance of density at high to extremely high levels. NDVI recorded an area of around 674,19 ha (high), while SAVI and NDWI reported 457.82 ha and 360.05 ha (extremely high), respectively.

Accuracy obtained reached 83.33% from 30 samples, indicating the effectiveness of remote sensing techniques. However, this study is limited by the number of samples and the need for more detailed field data. For further research, increasing the number of samples, using more complete field data, and exploring various combinations of classification methods is recommended. These findings provide an important scientific basis for mangrove forest conservation and rehabilitation policies in Bengkulu.

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