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Application of Remote Sensing for Mapping Vegetation Density Using Normalized Difference Vegetation Index (NDVI) in Langsa City Mangrove Forest

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Abstract: Mangroves are vital coastal ecosystems that thrive in tidal environments and play a crucial role in biodiversity and shoreline protection. This study aims to assess the vegetation density of the Langsa City Mangrove Forest using the Normalized Difference Vegetation Index (NDVI) derived from Sentinel-2A satellite imagery and analyzed through Geographic Information System (GIS) tools, particularly ArcGIS. NDVI values were categorized into four classes: very low (-0.15–0.34), low (0.35–0.48), medium (0.49–0.61), and high (0.62–0.83). The spatial analysis revealed that 57.2% of the area (approx. 128.5 ha) exhibited high vegetation density, while 24.6% (55.2 ha) showed medium density, and 13.3% (29.9 ha) had low vegetation. Approximately 4.9% (11.0 ha) of the area was classified as very low density, indicating regions with potential for ecological rehabilitation. These findings demonstrate that NDVI is an effective and reliable indicator for monitoring mangrove vegetation health. Routine application of NDVI analysis is essential for supporting sustainable management strategies and long-term conservation planning in coastal forest ecosystems..

Keywords: GIS; Langsa, Mangrove; NDVI; Remote sensing

Introduction

Mangroves are a type of shrub or tree that thrive in coastal areas with salty or brackish water (Rodiana et al., 2019). These forests play a crucial role in various ecological functions, providing essential services such as habitat for marine life, carbon sequestration, and coastal protection (Eddy et al., 2022). Mangroves are typically found along the coastlines of tropical and subtropical regions, often sheltered from wave action and wind, or located behind coral reefs (Purba et al., 2020). These forests are well adapted to survive in saline environments and are significantly influenced by tidal and wave movements (Dahlan et al. 2023). Their ability to thrive in extreme conditions, such as fluctuating salinity (ranging from 0-90%) and anoxic soils, showcases their remarkable adaptability (Spencer et al., 2016; Sasmito et al., 2020).

Mangroves are life-supporting systems that provide spawning grounds, nursery areas, and feeding habitats for various marine species (Heriyanto & Silvaliandra, 2019). Beyond their ecological benefits, mangroves also have significant economic value, serving as sources of firewood, food, and supporting eco-tourism activities (Susanti et al., 2024). The distribution of mangrove species is influenced by both natural factors such as tidal patterns and human activities like land use changes (Nelly et al., 2020). According to Senoaji & Hidayat (2016), in addition to their ecological roles, mangroves are important for local

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communities due to their economic contributions, making them crucial both for the environment and human livelihoods.

Langsa City, located in Aceh Province, covers an area of 262.41 km², and is home to a vast mangrove forest ecosystem. This area, primarily found in Langsa Barat District, spans approximately 6,000 hectares and is distributed along the coastline and river basins. Additionally, 119 hectares of this area are designated as a priority tourist zone (BPS Langsa, 2023). The environmental conditions and landscape in this area can be seen in (Figure 3, Figure 4). Langsa's mangrove forest is one of the largest in Southeast Asia and was recognized at the Anugerah Pesona Indonesia (API) Awards in 2019 in the Popular Ecotourism category. The presence of mangroves in Langsa is a strategic asset for economic development, particularly for industries like eco-tourism and fishing (Rahmadi et al., 2023).

To effectively monitor and manage this valuable ecosystem, remote sensing technology, combined with Geographic Information Systems (GIS) (Winarso, 2018), has become an essential tool. Remote sensing allows for the mapping and assessment of mangrove resources, including the monitoring of vegetation density and land use changes (Karmila et al., 2020). Satellite imagery, such as that from Sentinel-2, provides a cost-effective and high-resolution means of capturing data over large areas. This allows for precise analysis of vegetation health and distribution, offering valuable insights into ecosystem changes over time (Chen et al., 2019; Widyantara & Solihuddin, 2021). Remote sensing also enables the monitoring of remote or difficult-to-reach areas, making it an efficient tool for large-scale environmental management (Armanda et al., 2021).

Sentinel-2A satellite imagery, launched in June 2015, is widely used for land cover and land use mapping. It has 13 spectral bands, with spatial resolutions of 10 meters, 20 meters, and 60 meters, enabling detailed vegetation analysis (Kawamuna et al., 2017). Its ability to capture high-resolution imagery across a wide swath (290 km²) makes it an ideal choice for vegetation monitoring, particularly in coastal and mangrove ecosystems (Dharma et al., 2022).

One of the most widely adopted vegetation indices derived from Sentinel-2 data is the Normalized Difference Vegetation Index (NDVI), which has been proven effective in identifying vegetation health, density, and degradation patterns.

However, despite the strategic importance and vast coverage of Langsa's mangrove forest, quantitative studies using NDVI and spatial mapping techniques in this area remain limited. Previous research has not comprehensively examined vegetation density through NDVI classification nor quantified its distribution across Langsa's mangrove zones. This lack of detailed spatial and quantitative data represents a significant gap in the current literature. Studies that explicitly classify NDVI values and correlate them with mangrove health and ecosystem function in Langsa are virtually absent.

This study aims to address this gap by assessing the vegetation density of Langsa's mangrove forests using Sentinel-2A imagery and NDVI classification. Specifically, the research will produce spatial maps of NDVI classes—very low, low, medium, high, and very high density—along with their respective area coverage (in hectares), to generate accurate baseline data for conservation and management. The results are expected to contribute to sustainable mangrove ecosystem preservation by confirming that NDVI values are valid indicators for mangrove density monitoring and offering evidence-based inputs for future policy and environmental planning in eastern Aceh.

Method

Time and Location of Research

This study was conducted in the Mangrove Forest Area of Langsa, Langsa City, Aceh Province (Figure 1). Data collection and data processing and analysis stages took place from September 2024 to October 2024 in the Conservation Biology Laboratory of the Biology Department, Faculty of Mathematics and Natural Sciences, Syiah Kuala University, Banda Aceh.

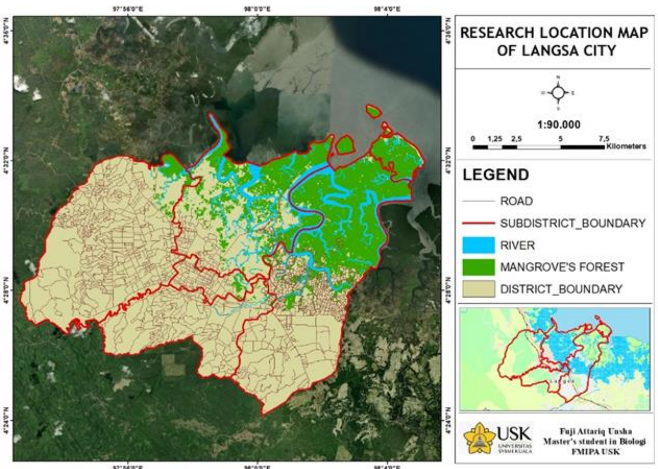

Figure 1. Research Location Map.

Tools and Materials

The research employed various tools, including a digital camera, Global Positioning System (GPS), observation sheets, Google Earth, writing materials, and a computer or laptop with ArcGIS 10.8 software. The study materials included shapefile data outlining the boundaries of Langsa City's mangrove forest area, administrative maps of Langsa City, and Sentinel-2A satellite imagery, which was accessed through Google Earth Engine.

Data Collection Method

This study employed a combination of remote sensing, Geographic Information Systems (GIS), and field survey techniques (Paembonanet et al., 2022). Primary data were collected in situ, including GPS-based point coordinates and physical parameters such as tree count, circumference, and species type to calculate mangrove density and frequency (Rahmadi et al., 2020). Secondary data consisted of Sentinel-2A imagery accessed via Google Earth Engine (GEE), using five key spectral bands—Blue, Green, Red, Near-Infrared (NIR), and Shortwave Infrared (SWIR)—along with supporting maps from national geospatial sources (RBI).

NDVI values were calculated using composite bands (Red, NIR, SWIR), followed by classification using the Iso Cluster Unsupervised method to delineate mangrove zones. Sentinel-2A imagery was retrieved via JavaScript-defined parameters in GEE, processed in ArcMap 10.8, and converted from raster to polygon format using Model Builder. Mangrove cover was then quantified in hectares for spatial analysis and validation (Dahlan et al. 2023). The coordinate system used was DGN 1995 Indonesia TM-3 Zone 47.1.

Table 1. The specifications of Sentinel-2 imagery (Dharma et al., 2022).

Sentinel 2 Band	Band	Central Wavelenght	Resolution
Coastal and Aerosol	1	0.443	60
Blue	2	0.490	10
Green	3	0.560	10
Red	4	0.665	10
Vegetation Red	5	0.705	20
Edge	6	0.740	20
Vegetation Red	7	0.783	20
Edge	8	0.842	10
Vegetation Red	8A	0.865	20
Edge	9	0.945	60
NIR	10	1.375	60
Vegetation Red	11	1.610	20
Edge	12	2.190	20
Water Vapour			
SWIR - Cirrus			
SWIR			
SWIR			

Data Analysis

The NDVI (Normalized Difference Vegetation Index) is used to compare the level of vegetation greenness using satellite data. The distribution of NDVI results is represented on a color scale ranging from green to red. Red indicates low index values, indicating areas with little to no vegetation, while green represents high index values, indicating areas with abundant and healthy vegetation. According to the vegetation index of each transformation model, negative values in NDVI suggest low vegetation levels. Specifically, when the NDVI value is less than zero, it indicates an area with minimal or no vegetation. This condition could signal deforestation, desert areas, or regions unable to support plant growth. Therefore, NDVI serves as a useful indicator for monitoring vegetation health and broad environmental changes, assisting in the management and monitoring of natural resources. This concept is an essential method in satellite image analysis for vegetation mapping and environmental change monitoring (Wisnhuputri et al. 2024). Shimu et al. (2019) used NDVI analysis to create a floristic index that identifies areas with dense vegetation, and it has also been widely used to monitor mangrove ecosystems. The NDVI formula, as stated by Rouse in 1973 and cited Sasmito & Suprayogi (2015), is as follows:

$$\text{NDVI} = \frac{BandNIR - BandR}{BandNIR + BandR} \quad (1)$$

Where:
NDVI = Normalized Difference Vegetation Index
NIR = Near Infrared
R = Red

NDVI values range from -1 to +1, with higher values indicating healthier and denser vegetation, while lower values represent areas with little or no vegetation, such as water, snow, or barren land. To determine the mangrove density, the NDVI values are reclassified into three classes: sparse, moderate, and dense, as shown in Table 2.

Table 2. The NDVI value range according to Rouse (1973) in Sasmito & Suprayogi (2015).

Class	NDVI Range	Category
1	0.61 – 1.00	High greenery
2	0.31 – < 0.60	Moderate greenery
3	0.00 – < 0.30	Moderate greenery
4	-1.00 – 0.00	Non Vegetated land

The data in the table above is also consistent with the statement by Tampubolon et al. (2019) that NDVI values range from -1 to 1. Water, bare land, buildings, and other non-vegetative elements are classified into the low NDVI (negative) range, while areas with high green vegetation fall into the high NDVI (positive) range, as shown in Table 2. This aligns with the statement by Philiani et al. (2016) that NDVI values range from -1 to 1, with values from -1 to 0 classified as non-vegetated, and values from 0 to 1 classified as vegetated areas.

Result and Discussion

NDVI stands for Normalized Difference Vegetation Index. It is an index used in remote sensing to assess the density and condition of vegetation in a specific area. NDVI is calculated using data from satellite imagery or other sensors that measure light reflectance at two specific wavelengths, namely red light (RED) and near-infrared (NIR) light (Purwanto, 2015). The measurement of carbon stock using Sentinel-2A satellite imagery involved NDVI (Normalized Difference Vegetation Index) analysis, combined with an Unsupervised Classification method for land use classification. After the NDVI-based land classification was completed, the next step was to convert the resulting raster data into vector format, which included points, lines, and polygons. These vector data were then used to calculate the area for each polygon through geometric calculations, using the "calculate geometry" function in the GIS software.

The NDVI values are indicative of mangrove density; higher NDVI values correspond to denser mangrove vegetation, which typically appears greener in satellite imagery. Denser vegetation is generally associated with higher carbon stock content. As a result, the NDVI analysis, combined with the land classification process, can estimate the carbon reserve content in the mangrove ecosystem. To gain a more comprehensive understanding of the vegetation conditions in the mangrove area, specific details regarding the NDVI values are presented in Table 3.

Table 3. NDVI Classification Values of Mangroves in Langsa City.

Class	NDVI Range	Category	Description
1	(-0.15) – 0.34	Non-vegetated land	No or very little vegetation
2	0.35 – 0.48	Low greenery	Vegetation present, but not very dense
3	0.49 – 0.61	Moderate greenery	Vegetation is fairly dense
4	0.62 – 0.83	High greenery	Vegetation is fairly dense and healthy

Vegetation indices are formulas used in remote sensing data processing to analyze thematic information about land areas covered with vegetation. Several types of vegetation indices exist, such as NDVI (Normalized Difference Vegetation Index), GI (Green Index), and WI (Wetness Index) (Ruslana & Sulistyowati, 2020). In this study, the vegetation index applied is NDVI. To analyze changes in mangrove land area, the GIS program used the Shapefile (SHP) format, while the NDVI technique was employed to assess vegetation density (Rosalina et al., 2023). NDVI is a widely-used index that compares the reflectance of near-infrared (NIR) light to red (R) light from a specific area to measure vegetation coverage and health (Hidayati et al., 2019).

Research by Prayudha et al. (2023) shows that variations in the wavelengths of light reflected or absorbed by mangrove plants can provide significant insights into their physical and biochemical traits. For instance, near-infrared (NIR) light is often used to evaluate chlorophyll content in plants because chlorophyll absorbs light in this range, while shortwave infrared (SWIR) wavelengths offer valuable information about the water content in plants. Therefore, spectral analysis of light reflected by mangrove vegetation across different wavelengths is essential for distinguishing and understanding the biological and environmental aspects of mangrove ecosystems.

The distribution of NDVI values is based on vegetation class classification, where most land use consists of vegetation, bare land, wetlands, shrubs, and water bodies. Class 1 represents areas with no vegetation or sparse vegetation. Class 2 refers to areas with low vegetation greenness. Class 3 indicates areas with moderate vegetation greenness. Class 4 represents mangrove vegetation areas with high greenness. A distribution map with these value ranges can be seen in the following Figure 2.

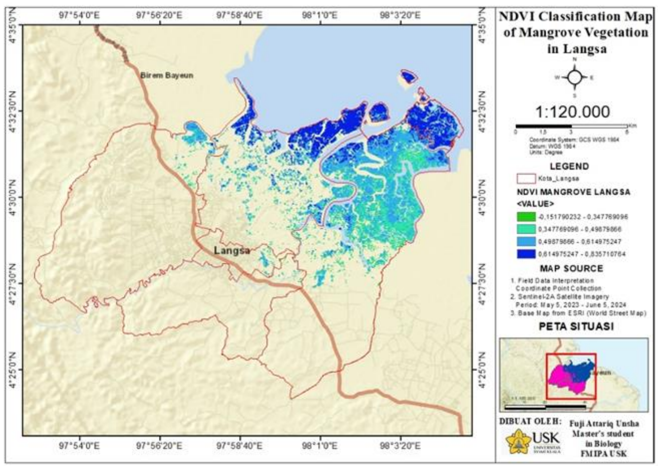

Figure 2. NDVI Classification Map

Based on the NDVI analysis of the Langsa Mangrove Forest area, it can be observed that this region shows the presence of lush and healthy mangrove vegetation, indicated by a high level of greenness, as seen in Figures 2. However, there are some small areas with moderate or low NDVI values. These NDVI values are classified into four categories: non-vegetated, low density, moderate density, and high density. Typically, vegetation indices are used to detect vegetation such as mangrove density. This vegetation index is applied to satellite imagery to highlight aspects of vegetation density or other related features. The high level of greenness indicates the significant potential of the mangrove area to act as a substantial carbon sink. According to Purwanto et al. (2014), the NDVI index value is used to determine mangrove density based on the level of vegetation greenness. The high greenness observed in the Langsa mangrove area reflects good vegetation condition and a significant potential for carbon storage. The presence of dense and healthy vegetation in mangrove forests signals high productivity in absorbing carbon from the atmosphere. Additionally, mangroves are known to be one of the most efficient ecosystems in carbon storage, both in the soil and in plant biomass.

NDVI utilizes the difference between near-infrared (NIR) reflectance and red (Red) reflectance from objects in the image. NIR wavelengths influence the chlorophyll content in vegetation. By using NDVI, mangrove vegetation can be more clearly distinguished, as it typically has higher NDVI values, indicating a higher presence of chlorophyll. This allows for the estimation of the carbon stock potential in the mangrove vegetation. NDVI is also a standard product of NOAA (National Oceanic and Atmospheric Administration), the organization that manages weather satellites orbiting the Earth. Therefore, this value is crucial in vegetation mapping and monitoring, including mangrove ecosystems.

The processing of NDVI for mangrove vegetation involves the use of data from specific bands, such as band 4 (red), band 5 (near-infrared), and band 11 (shortwave infrared). The goal of this process is to generate a visualization in RGB (Red Green Blue) format, enabling the differentiation between mangrove vegetation and other terrestrial plants. The digital values of the Normalized Difference Vegetation Index (NDVI) can be used to estimate the presence of mangrove vegetation in a particular area. Comprehensive information about the condition of the vegetation can be obtained from the resulting NDVI values (Mayuftia et al., 2013). This is in line with the statement by Annisa et al. (2019) that image enhancement is performed to improve object clarity in images, making the objects sharper and more distinct.

NDVI values also influence land use. NDVI serves as an indicator to measure vegetation density and plant health from satellite imagery. The NDVI values range from -1 to +1, where higher values indicate denser vegetation. Therefore, NDVI is highly useful for understanding land use, particularly in determining vegetation distribution and identifying different types of land use, such as forests, agricultural areas, or built-up land. The higher the NDVI value, the greater the mangrove density, indicating a larger number of mangrove individuals within that pixel. This means that areas with high NDVI have more fertile conditions that support denser mangrove vegetation growth. High NDVI values indicate sufficient moisture and healthy vegetation, which are crucial for mangrove survival. On the other hand, low NDVI values indicate a lack of vegetation or land use that is not green (Pratama et al., 2016).

Figure 3. Evidence of spot logging in the mangrove areas of Langsa City, Aceh, Indonesia

Figure 4. Four mangrove species in the mangrove areas of Langsa City, Aceh, Indonesia

Conclusion

The NDVI values in the Langsa Mangrove Forest range from a minimum of -0.15 to a maximum of 0.83. The high NDVI values observed in the Langsa Mangrove area indicate that the mangroves are lush and in good condition. These values reflect healthy and dense vegetation, which signifies a thriving ecosystem. The high NDVI further emphasizes the area's potential for carbon storage, as mangroves are known for their efficiency in sequestering carbon. Overall, the high NDVI values in Langsa suggest that the mangrove forests are flourishing and provide an essential ecosystem service, underlining the importance of their conservation and sustainable management.To ensure long-term ecosystem integrity, these findings advocate for the integration of NDVI-based remote sensing into environmental education programs and policy frameworks for continuous monitoring and adaptive management of coastal ecosystems.

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Author Contributions

Fuji Attariq Unsha was responsible for the conceptualization, methodology, formal analysis, investigation, data curation, and writing—original draft preparation. Saida Rasnovi contributed to supervision, validation, writing—review and editing, and visualization. Dahlan was involved in providing resources, software, and methodology, as well as contributing to writing—review and editing and project administration. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Annisa, A. Y. N., Pribadi, R., & Pratikto, I. (2019). Analysis of Mangrove Forest Area Changes in Brebes and Wanasari Districts, Brebes Regency, Using Landsat Satellite Imagery from 2008, 2013, and 2018. *Journal of Marine Research*, 8(1): 27–35. https://doi.org/10.14710/jmr.v8i1.24323.

Armanda, A., Mubarak, M., & Elizal, E. (2021). Analysis of land cover changes in mangrove vegetation using landsat image data in Coastal, Sungai Apit District, Siak Regency, Riau Province. *Asian Journal of Aquatic Sciences,* 4, 154–162. https://doi.org/10.31258/ajoas.4.2.154-162.

Badan Pusat Statistik Kota Langsa. (2023). Kota Langsa Dalam Angka. Badan Pusat Statistik Langsa, Aceh.

Chen Y, Guerschman JP, Cheng Z, You L. (2019). Remote sensing for vegetation monitoring in carbon capture storage regions: A review. *JApplTechnol* 240: 312-346. https://doi.org/10.1016/j.apenergy.2019.02.027.

Dahlan D, Jaya INS, Saleh MB, Puspaningsih N, Affan M. (2023). Developing a spatial mathematical model for assessing the rate of natural forest changes. Aceh International Journal of Science and Technology 12 (1): 14-24. https://doi.org/10.13170/aijst.12.1.31703 .

Dahlan D, Jaya INS, Saleh MB, Puspaningsih N, Sutekad D. (2023). Typology and deforestation of lowland tropical rain forests. *International Journal of Applied Science and Engineering Review (IJASER)* 4(1): 32-47. https://doi.org/10.52267/IJASER.2023.4304.

Devara T, Wijayanto, AW. (2021). Machine learning applied to sentinel-2 and landsat-8 multispectral and medium-resolution satellite imagery for the detection of rice production areas in Nganjuk, East Java, Indonesia. *International Journal of Remote Sensing and Earth Sciences (IJReSES)* 18 (1): 19-32. https://doi.org/10.30536/j.ijreses.2021.v18.a3538.

Dharma, F., Aulia, A., Shubhan, F., & Ridwana, R. (2022). Utilization of Sentinel-2 Imagery with NDVI Method for Mangrove Vegetation Density Change in Indramayu Regency. Jurnal Pendidikan Geografi Undiksha, 10, 155–165.

Eddy S, Dahlianah I, Mahito C, Oktavia M, Utomo B. (2022). Anthropogenic implications for land cover changes and vegetation structure in coastal protected forests. *Biodiversity* 23 (9): 4473-4481. https://doi.org/10.13057/biodiv/d230913.

Heriyanto N, Silvaliandra V. (2019). Mangrove diversity and carbon stock in Lepar Pongok Islands, South Bangka District. *Buletin Plasma Nutfah* 25 (2): 123–132. https://doi.org/10.21082/blpn.v25n2.2019.p47-58.

Hidayati IN, Suharyadi R, Danoedoro P. (2019). Exploring spectral index band and vegetation indices for estimating vegetation area. *Indonesian Journal of Geography* 50 (2): 211–221. https://doi.org/10.22146/ijg.38981.

Karmila D, Jauhari A, Kanti R. (2020). Estimasi nilai cadangan karbon menggunakan analisis NDVI (Normalized Difference Vegetation Index) di KHDTK Universitas Lambung Mangkurat. *Jurnal Sylva Scienteae* 3 (3): 451-459. https://doi.org/10.20527/jss.v3i3.2178.

Katili AS, Ibrahim M, Zakaria Z. (2017). Degradation level of mangrove forest and its reduction strategy in Tabongo Village, Boalemo District, Gorontalo Province, Indonesia. *Asian Journal of Forestry* 1 (1): 18-22. https://doi.org/10.13057/asianjfor/r010102.

Kawamuna, A., Suprayogi, A., & Wijaya, A. P. (2017). Analysis of Mangrove Forest Health Based on NDVI Classification Method Using Sentinel-2 Imagery. *Jurnal Geodesi Undip*, January 2017, 6, 277–284. https://doi.org/10.14710/jgundip.2017.15439.

Mayuftia, R., Hendrarto, B., & Hartoko, A. (2013). Mangrove Damage Level and Carbon Assessment Using NDVI (Normalized Difference Vegetation Index) Satellite Data in Sidodadi Village, Pesawaran Regency, Lampung Province. *Management of Aquatic Resources Journal (MAQUARES),* 2, 146–154. https://doi.org/10.14710/marj.v2i4.4278.

Nelly C, Rasnovi S, Zumaidar Z. (2020). Mangrove ecosystem suitability for ecotourism management recommendation in Iboih Village–Sabang. *In E3S Web of Conferences 151:* 1-6. https://doi.org/10.1051/e3sconf/202015101060.

Paembonan RE., Achmad MD., Marus I., Baddu S., Karman A., Najamuddin N., & Ismail F. (2022). Mangrove forests on Ternate Island spatially and temporally. *Journal of Archipelagic Marine Science,* 5(2), 656-667. https://doi.org/10.46252/jsai-fpik-unipa.2024.Vol.8.No.4.412.

Philiani I., Saputra L., Harvianto L., & Muzaki AA. (2016). Mapping of Mangrove Forest Vegetation

Using the NDVI Method. *Surya Octagon Interdisciplinary Journal of Technology*, 1: 211–222. https://doi.org/10.31219/osf.io/c8k6j.

Pratama, M. I., Delvian, D., & Hartini, K. S. (2016). Vegetation Structure and Carbon Stock of Stands in the Lembah Harau Nature Reserve Forest Area, Lima Puluh Kota, West Sumatra. Peronema Forestry Science Journal, 5, 19–27.

Prayudha B, Ulumuddin YI, Siregar V, Suyarso, Agus SB, Prasetyo LB, Anggraini K, Salatalohi A. (2023). Geomorphological and hydrological changes play a critical role in mangrove forest degradation in a rapidly shrinking lagoon in Indonesia. *AACL Bioflux* 16 (1): 151–167. https://doi.org/10.1016/j.mex.2024.102778.

Purba, A., Kesumawati, D., Rambe, T. R., & Zuliani, U. S., Parinduri, W. M., Irwanto. (2020). Mangrove Ecosystem Management Considering Water Quality Based on Chemical Properties in Jaring Halus Village. *Jurnal Pengabdian Kepada Masyarakat (JPKM),* 1, 54–59.

Purwanto, A. (2015). Utilization of Landsat 8 Imagery for Identifying the Normalized Difference Vegetation Index (NDVI) in Silat Hilir District, Kapuas Hulu Regency. *Edukasi: Jurnal Pendidikan*, 13(1): 27–36. https://doi.org/10.31571/edukasi.v13i1.17.

Purwanto, A. D., Asriningrum, W., Winarso, G., & Parwati, E. (2014). Analysis of Mangrove Distribution and Density Using Landsat 8 Imagery in Segara Anakan, Cilacap. *In Proceedings of the 2014 National Remote Sensing Seminar* (pp. 232-241). LAPAN.

Rahmadi MT, Yuniastuti E, Suciani A, Harefa MS, Persada AY, Tuhono E. 2023. Threats to mangrove ecosystems and their impact on coastal biodiversity: A study on mangrove management in Langsa City. *Indonesian Journal of Earth Sciences* 3 (2): 1-14. https://doi.org/10.52562/injoes.2023.627.

Rahmadi MT., Suciani A., & Auliani N. (2020). Analysis of Mangrove Forest Area Changes Using Landsat 8 OLI Imagery in Lubuk Kertang Village, Langkat. *Geographical Communication Media*, 21(2), 110-119. https://doi.org/10.23887/mkg.v21i2.24197.

Rodiana L., Yulianda F. & Sulistiono. (2019). Suitability and Ecological Carrying Capacity of Mangrove-Based Ecotourism in Teluk Pangpang, Banyuwangi. *JFMR-Journal of Fisheries and Marine Research*, 3(2): 77–88. https://doi.org/10.21776/ub.jfmr.2019.003.02.10.

Rosalina D, Hawati H, Rombe, KH, Surachmat A, Awaluddin A, Amiluddin M, Asriyanti, A. (2023). Application of remote sensing and GIS for mapping changes in land area and mangrove density in the Kuri Caddi Mangrove tourism, South Sulawesi Province, *Indonesia. Biodiversitas Journal of* Biological *Diversity* 24 (2): 1049-1056. https://doi.org/10.13057/biodiv/d240246.

Ruslana ZN & Sulistyowati. (2020). Analysis of vegetation density index for identifying tornado occurrences and potential in Klaten Regency. *Megascience* 11: 1–12. https://doi.org/10.46824/megasains.v11i02.9.

Sasmito B, Suprayogi A. (2015). Model spasial aliran permukaan dan monitoring tutupan lahan di Kota Semarang. *Jurnal Ilmiah Geomatika* 21: 1–8. DOI: 10.24895/JIG.2015.21-1.469.

Sasmito SD, Kuzyakov Y, Lubis AA, Murdiyarso D, Hutley LB, Bachri S, Friess DA, Martius C, Borchard N. (2020). *Organic carbon burial and sources in soils of coastal mudflat and mangrove ecosystems*. Catena 187: 1-11. https://doi.org/10.1016/j.catena.2019.104414.

Senoaji G., & Hidayat MF. (2016). The Role of Mangrove Ecosystems on the Coast of Bengkulu City in Mitigating Global Warming Through Carbon Storage. *Journal of Human and Environment*, 23(3): 327-333. https://doi.org/10.22146/jml.18806.

Shimu SA, Aktar M., Afjal MI, Nitu AM, Uddin MP, Al Mamun M. (2019). NDVI based change detection in Sundarban Mangrove Forest Using Remote Sensing Data. *4th International Conference on Electrical Information and Communication Technology (EICT 2019 IEEE)* 1: 1-5. https://doi.org/10.1109/EICT48899.2019.9068819.

Spencer T, Moller I., & Reef R. (2016). Mangrove Systems and Environments. In Reference Module in Earth Systems and Environmental Sciences. Elsevier, Amsterdam.

Susanti R, Kadarisman Y, Asriwandari H, Putri OA. (2024). The movement of outermost small island community groups in mangrove conservation in the North Rupat District Bengkalis Regency. *JHSS (Journal of Humanities and Social Studies)* 8 (1): 318-323. https://doi.org/10.33751/jhss.v8i2.9920.

Tampubolon T., Juliani R., & Hutahaean J. (2019). Utilization of Landsat Satellite Imagery to observe environmental change at Sinabung Mountain Area. *AISTSSE*, 18, 1-7. https://doi.org/10.4108/eai.18-10-2018.2287308.

Widyantara AP, Solihuddin T. (2020). Mapping mangrove land area changes in the probolinggo coast using satellite imagery. *Jurnal Penginderaan Jauh dan Pengolahan Data Citra Digital* 17: 75–87. https://doi.org/10.30536/j.pjpdcd.2020.v17.a3216.

Winarso G. 2018. Rapid method for mangrove forest monitoring using remote sensing data. *Seminar Nasional Geomatika,* 1: 901–910. https://doi.org/10.24895/SNG.2018.3-0.1056.

Wishnuputri S, Withaningsih S, Parikesit P. (2024). Estimation of carbon stock in mixed garden tree stands in Jatigede Subdistrict, Sumedang Regency using NDVI (Normalized Difference Vegetation Index). *In E3S Web of Conferences* 495: 1-9. https://doi.org/10.1051/e3sconf/202449502005.