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Analysis of Mangrove Density using NDVI and Macrobenthos Diversity in Ampekale Tourism Village South Sulawesi, Indonesia

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ABSTRACT

The mangrove ecosystem faces significant challenges, as its quality and quantity are threatened with decline. This study aimed to analyze the mangrove density and macrobenthos diversity in the Ampekale Ecotourism Village, Indonesia. This research utilizes remote sensing image analysis through the Normalized Difference Vegetation Index (NDVI) method. Complementary ground-check surveys were conducted to ascertain the density and diversity of mangrove and macrobenthos species. The overall mangrove density in the Ampekale area was relatively high, with some areas displaying moderate density. The sequence of mangrove species, from most common to least common, includes *Rhizophora mucronata, Avicennia marina, Avicennia alba, Rhizophora apiculata, Sonneratia alba, Bruguiera gymnorhiza,* and *Acanthus ilicifolius*. The most prevalent macrobenthos belong to the Crustacea class, such as *Uca* sp., *Sesarma*, *Metaplax* sp., and *Scylla serrata*. Moreover, the most diverse macrobenthos belong to the Gastropods class. The distribution of this biodiversity depends on their location (coastal or inland), tidal fluctuations, and river estuaries. Mangrove ecosystems situated in estuaries with high densities exhibited elevated macrobenthos abundance. This correlation suggests that areas characterized by dense mangroves also harbor stable ecosystem conditions with abundant macrobenthos. In contrast, ecosystems featuring lower biodiversity demonstrated reduced stability. These findings contribute valuable insights into the conservation and sustainability of mangrove ecosystems.

1. Introduction

Mangrove density is a parameter to estimate the density of mangroves in a particular area so that it can provide information on the abundance and growth potential of mangroves in an area (Marasabessy et al. 2021). Mangroves constitute vital coastal ecosystems that play a pivotal role in upholding ecological equilibrium and safeguarding coastal regions against tidal waves (Sreelekshmi et al. 2018), abrasion threats (Piekkoontod et al. 2020), coastal erosion (Gracia et al. 2018), and tsunamis. Possessing a rich diversity of flora and fauna, most coastal areas inherently possess the potential to foster regional development encompassing industrial, maritime, and tourism activities (Chen et al. 2017; Tan et al. 2023) due to their inherent aesthetic value (Machava-António et al. 2022).

Mangrove forests provide an array of ecosystem services, encompassing timber products such as lumber, poles, firewood, and charcoal, as well as non-timber products such as salt production, tannins, beekeeping for honey production, fisheries, aquaculture, medicines, and cultural values (Valderrama-Landeros et al. 2018; Yudha et al. 2022). The mangrove ecosystem has local and global impacts, including offering habitats for diverse animal species, conserving rare animals, contributing to the carbon cycle, and facilitating other biogeochemical processes (Zakaria and Rajpar 2015). Mangrove forests are pivotal in trophic chains (Muro-Torres et al. 2020). However, these ecosystems have experienced a decline in both quality and quantity due to environmental degradation stemming from anthropogenic disturbances, land use alterations, shrimp farming, climate change, and sea level rise (Alatorre et al. 2016; Arfan et al. 2023; Chen et al. 2017; Purnomo et al. 2013). Consequently, it is imperative to address hazards, alleviate potential consequences, and sustain the stability of mangrove ecosystems (Tan et al. 2023).

Indonesia has diverse mangrove species, with 19% of the total global mangrove expanse (Purnomo et al. 2013). It also boasts the highest biomass and holds a substantial carbon sink capacity (Suwanto et al. 2021). One particularly noteworthy area in Indonesia, renowned for its significant mangrove ecosystem potential, is Ampekale Tourism Village. Situated along the coastal region of Maros Regency, this village directly faces the Makassar Strait and is enveloped by mangrove forests along its shoreline. This locale presents remarkable potential as an ecotourism destination that showcases breathtaking mangrove vistas and biodiversity. The village's remarkable biodiversity and unique ecosystem not only captivate researchers but also entice tourists who are interested in exploring the mangroves.

Mangroves encompass vegetative land cover. In addition to field measurements undertaken by Heriyanto et al. (2023) who gauged vegetation density in urban areas, satellite data can also be employed. Modern advancements in information and geospatial technology have ushered in a more efficient, effective, and precise approach to monitoring land cover (Sukri et al. 2023), exemplified by remote sensing technology. Employing remote sensing techniques based on satellite imagery for land cover mapping has gained widespread traction and is often a dependable alternative to conventional field survey mapping methods.

Numerous studies have harnessed satellite imagery to delineate vegetation zones, including evaluating green areas in urban settings utilizing the Normalized Difference Vegetation Index (NDVI) analysis (Huyen et al. 2022). Chu et al. (2019) scrutinized NDVI-based vegetation dynamics in Heilongjiang. Shimu et al. (2019) employed NDVI analysis to create a floristic index indicative of highly vegetated zones. NDVI has also been extensively leveraged to monitor mangrove areas; for example, Alatorre et al. (2016) utilized NDVI analysis on Landsat images to assess the health of mangrove forests impacted by shrimp farming. Furthermore, Valderrama-Landeros et al. (2018) charted the condition of mangroves along the Pacific coast using Sentinel-2 imagery, demonstrating superior accuracy compared to Landsat image classification. NDVI and Sentinel-2A imageries present a more efficient and accurate method for estimating vegetation density across various ecosystems, including mangroves.

Managing mangrove areas within specific sectors without considering the available potential may precipitate environmental degradation and the depletion of natural resources (Buwono 2017). In mangrove area management, a fundamental step involves studying and assessing the area's condition and potential. Monitoring mangrove density and the fauna's biodiversity therein serves as an indicator for discerning the mangrove ecosystem's health (Sari et al. 2019). Murniasih et al. (2022) investigated mangrove density in support of *Crocodylus porosus* conservation within the

Kali Ijo Estuary. Gazali et al. (2019) explored the relationship between mangrove density and gastropod presence in Tarakan. The pivotal role of mangrove ecosystems in biodiversity is underscored by the fact that many animal species rely on them (Roslinda et al. 2021). Diminished mangrove ecosystem quality correlates with reduced biota presence and diversity (Laraswati et al. 2020).

This study aims to analyze mangrove density and Macrobenthos diversity in Ampekale Village, Indonesia. The information on mangrove density can provide valuable insights for area managers, stakeholders, and communities engaged in conservation and sustainable ecotourism management efforts. This article delves into the research process, the methodology adopted for NDVI analysis of Sentinel-2A images to estimate mangrove density, and the consequential findings that bear significance in ecosystem preservation and mangrove tourism advancement.

2. Materials and Methods

2.1. Study Area

This research was conducted within the mangrove area of Ampekale Village, situated in Maros Regency, South Sulawesi Province, Indonesia. Geographically, the village is positioned in the northern sector of Sulawesi Island, with its geographical coordinates spanning from latitude 4°54' South to 5°1' South and longitude 119°32' East to 119°39' East. A blend of mountains and hills defines the topography of Ampekale Village. Encompassed by verdant forests, including mangrove forests, the village's environs offer refreshing air and tranquil vistas. The presence of rivers meandering around the village contributes to its inherent natural charm, rendering it an ideal destination for tourism.

In terms of climate, Ampekale Village falls within the tropical climate category, distinctly marked by alternating rainy and dry seasons. The rainy season typically extends from November to March, while the dry season spans from April to October. The mean daily temperature in the region remains within the range of 25°C to 30°C throughout the year (BPS 2023). With its diverse topography and tropical climate, Ampekale Village in Maros Regency stands distinguished by its distinctive natural landscape and climatic milieu. The geographical location of the research site is illustrated in **Fig 1**.

2.2. Data

The data utilized for this research are sourced from both remote sensing and field surveys. Remote sensing data were acquired through Sentinel-2A images from 2022, procured through EarthExplorer (https://earthexplorer.usgs.gov/). Field survey data encompassed the identification of mangrove species through the deployment of an uncrewed aerial vehicle (UAV) and the assessment of Macrobenthos using the transect method. Data processing was conducted using a combination of Remote Sensing (RS) and Geographic Information Systems (GIS), specifically Google Earth Engine and Quantum GIS (QGIS). RS is renowned for its effectiveness and efficiency in discerning objects and phenomena across the Earth's surface, while GIS is powerful in representing them (Yusuf et al. 2022). The methodological flow chart illustrating the research approach is presented in **Fig. 2**.

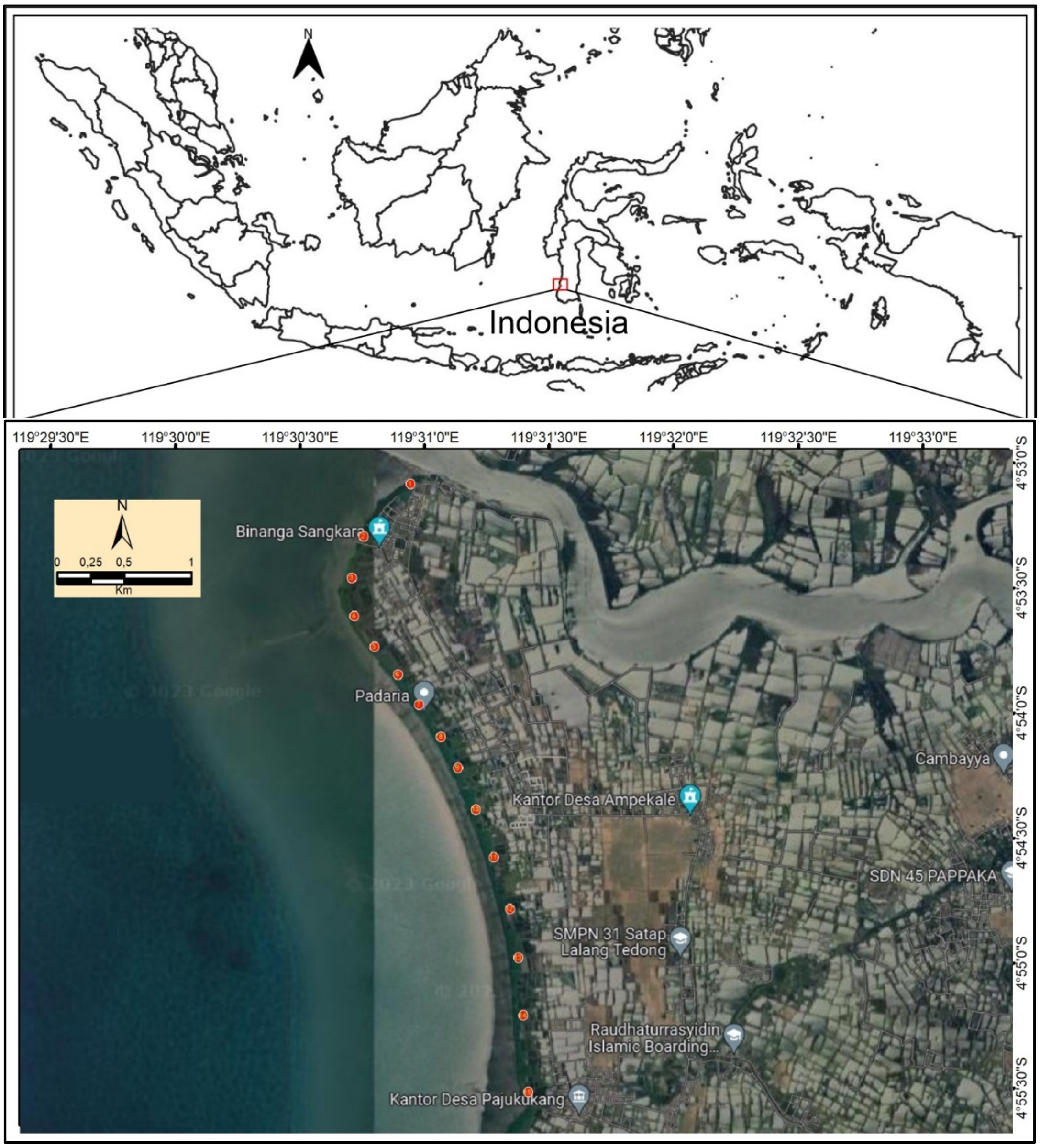

Fig. 1. Location and observation station in Ampekale Village, Indonesia (Source: Basemap imagery from ArcGIS Online).

2.3. NDVI Analysis

Mangrove density analysis was centered on quantifying mangrove trees within a given location. This assessment employed the Normalized Difference Vegetation Index (NDVI) method, a valuable tool for gauging vegetation density, including mangroves. This method leverages specific channels within Sentinel-2A images, utilizing the reflection characteristics of objects in band 8 (near infrared) and band 4 (red spectrum). The NDVI methodology discerned vegetation from other surfaces by contrasting the absorption of red wavelengths by chlorophyll and the near-infrared (NIR) reflectance exhibited by green vegetation (Huyen et al. 2022). The computation of NDVI is expressed in Equation 1.

$$NDVI = \frac{(B8 - B4)}{(B8 + B4)} \quad (1)$$

NDVI for the Sentinel-2A image was determined by taking the difference between the values of bands 8 and 4, divided by the sum of the values of bands 8 and 4. This process generates NDVI values categorized into density classes: dense, moderate, and sparse. The classification is based on NDVI ranges, namely 0.28–0.32 (sparse), 0.33–0.42 (moderate), and 0.43–1.00 (dense). The outcome of this analysis is the creation of a mangrove density map.

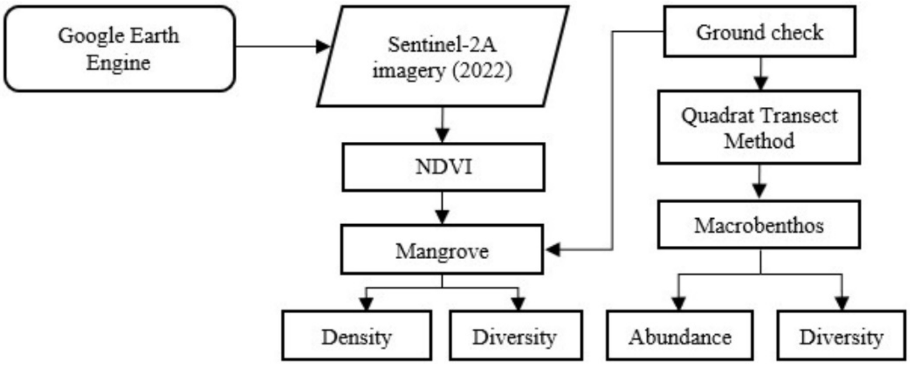

Fig. 2 Methodological flow chart.

2.4. Ground Check

Ground check activities supplement the assessment by offering an on-site understanding of the ecosystem's state. Data was collected through ground checks encompassing aspects such as mangrove species, mangrove density, and the abundance and diversity of macrobenthos. The ecological approach applied during ground checks involves the quadrat transect method. To measure the abundance and diversity of flora and fauna within the ecosystem, the plot method, a refinement of the Mueller method (Renta et al. 2016; Warpur 2016), was employed. Each plot or transect has a size of 10 m × 10 m. The number of macrobenthos was counted as the number of species within the transect. Observations were conducted during low tide to facilitate macrobenthos observation. The abundance of macrobenthos was quantified using Equation 2, and the macrobenthos diversity was calculated using Equation 3.

$$K = \frac{\textit{Number of macrobenthos}}{\textit{Transect plot area } (m^2)} \quad (2)$$

$$H' = \log N - \frac{1}{N}\sum ni \log ni \quad (3)$$

where N represents the total number of samples, and ni denotes the number of occurrences of each species. This approach enables a comprehensive assessment of mangrove ecosystem characteristics.

3. Results and Discussion

3.1. Mangrove Density

The analysis of mangrove density can be effectively conducted through geographic information systems, explicitly employing Landsat image analysis and the NDVI method. The outcomes of the NDVI analysis of mangrove density within the Ampekale Mangrove Area are visually presented in **Fig. 3**. Furthermore, a ground check was undertaken to ascertain the accuracy of the NDVI results and to observe the various types of mangroves present in the study location. The results of the mangrove ground check are presented in **Table 1**.

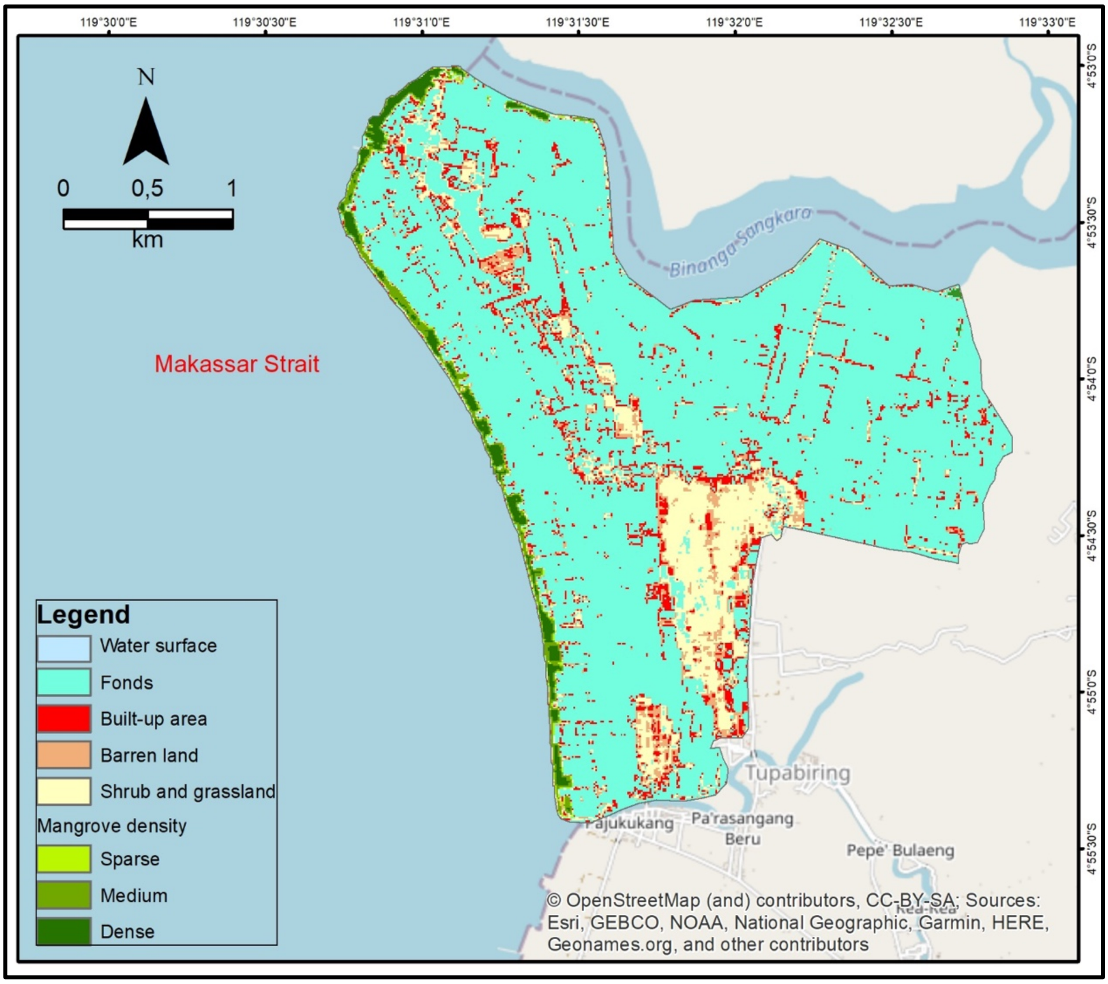

Fig. 3. Mangrove density derived from NDVI analysis results in the Ampekale Area.

Table 1. Observation stations for ground check

Station	Mangrove density	Mangroves Found
1	Dense	*Rhizophora mucronata, Avicennia alba, Avicennia marina, Rhizopohora apiculata, Sonneratia alba, Bruguiera gymnorhiza, Achantus ilicilicifolius*
2	Dense	
3	Moderate	
4	Dense	
5	Dense	
6	Moderate	
7	Dense	
8	Moderate	
9	Dense	
10	Moderate	
11	Moderate	
12	Dense	
13	Dense	
14	Moderate	
15	Moderate	

Based on the findings of the on-site ground check within the Ampekale Mangrove Area, it is evident that mangroves generally exhibit high density, with specific areas characterized by medium density. The mangrove species present in this study site are attributed to the families

Rhizoporaceae, Acanthaceae, and Lythraceae. Predominantly, the mangrove species *Rhizophora mucronata* takes precedence, closely followed by *Avicennia marina* and *Avicennia alba*. Although in limited numbers, additional species encompass *Rhizophora apiculata*, *Sonneratia alba*, *Bruguiera gymnorrhiza*, and *Achantus ilicifolius*. These findings resonate with the perspectives offered by Nugroho et al. (2018), indicating that areas close to the sea, often featuring sandy substrates, are commonly populated by *Avicennia* sp., *Rhizophora* sp., and *Sonneratia* sp., succeeded by *Bruguiera* sp. Substrate suitability significantly influences mangrove density (Abubakar et al. 2022).

The mangroves within the Ampekale Mangrove Area are predominantly populated by *R. mucronata*, followed by *A. marina*. A similar trend was reported by Suwanto et al. (2021), who identified *R. mucronata* and *A. marina* as the most dominant mangrove species in Subang Regency, Indonesia. However, distinct findings were documented by Ledheng et al. (2022) in the North Central Timor Regency, where *R. mucronata* and *R. apiculata* emerged as the dominant species. A parallel observation was recorded by Murniasih et al. (2022) in Muara Kali Ijo. The prevalence of *R. mucronata* can be attributed to its higher tolerance toward firm, sandy substrates. Particularly dense patches of *R. mucronata* were detected in plots 1, 2, 4, and 15, coinciding with river estuaries. This aligns with the assertions of Herison and Yuda (2020) that *R. mucronata* thrives in tidal riverbanks and estuaries. Nearly all points in the study area exhibited the presence of *Rhizophora* sp., aligning with the observations of Suwanto et al. (2021), who noted that *Rhizophora* sp. typically inhabits the coastal fringe, thriving in environments characterized by prolonged inundation. The adaptability of *Rhizophora* sp. to sandy and muddy soil substrates aids its successful growth and propagation (Buwono 2017).

In plots 5, 7, 9, 11, and 12, situated close to the shoreline, *A. marina* (of the Acanthaceae family) prevails. The prominence of *A. marina* in these areas is due to the influence of tides. This phenomenon concurs with the observations of Herison and Yuda (2020), who indicated that *A. marina* can only flourish in locations subject to tidal impact. This type of mangrove adapts by developing specialized roots (pneumatophores) that facilitate respiration in oxygen-depleted, muddy soils characteristic of tidal zones.

According to Sreelekshmi et al. (2018), the distribution and zonation patterns of mangroves are intrinsically linked to geographical factors, including their marine or terrestrial location, the frequency of tidal inundation, and the presence of freshwater channels (such as rivers). Generally, marine assemblages encompass species like Avicennia, Sonneratia, and Rhizophora, while inland assemblages tend to feature Bruguiera species. *B. gymnorrhiza*, in particular, is confined to inland areas. Species such as *R. mucronata*, *R. apiculata*, and *A. alba* are primarily found within fringe areas and seldom in other regions. *S. alba* is encountered within both fringe and transitional zones.

3.2. Macrobenthos Diversity

The macrobenthos fauna observed in the study site encompassed 17 species, classified into 3 distinct classes: Gastropod, Crustacea, and Bivalvia. Under the Gastropod class, notable species included *Telescopium mauritsi*, *Crepidula convexa*, *Melanoides* sp., *Pedipes mirabillis*, *Cerithidea quadrata*, *Terebia* sp., *Nassarius albus*, *Natica* sp., *Nerita* sp., and *Littorina* sp. Moving to the Crustacea class, prominent findings encompassed *Uca* sp., *Episaserma* sp., *Metaplax* sp., and *Scylla serrata*. Finally, within the Bivalvia class, the identified species consisted of *Nucula* *verrilli*, *Saccostrea* sp., and *Pilsbryooncha exilis*. The abundances and diversities of macrobenthos at each observation station are systematically presented in **Table 2**.

Table 2. Abundance and diversity of macrobenthos in the Ampekale Mangrove Area, Indonesia

Station	Macrobenthos			Total	Abundance		Diversity	
	Bivalvia	Gastropod	Crustacea		Index	Category	Index	Category
1	17	47	42	106	1.06	High	3.19	High
2	6	43	33	82	0.82	High	2.29	Moderate
3	7	36	37	80	0.80	High	2.57	Moderate
4	23	38	64	125	1.25	High	2.55	Moderate
5	20	43	41	104	1.04	High	2.93	Moderate
6	29	33	22	84	0.84	High	1.96	Low
7	13	55	35	103	1.03	High	2.85	Moderate
8	6	56	9	71	0.71	Moderate	2.65	Moderate
9	6	57	40	103	1.03	High	2.51	Moderate
10	6	46	20	72	0.72	Moderate	2.13	Moderate
11	10	45	19	74	0.74	Moderate	2.10	Moderate
12	12	48	30	90	0.90	High	2.07	Moderate
13	15	34	18	67	0.67	Moderate	2.05	Moderate
14	17	36	18	71	0.71	Moderate	2.04	Moderate
15	7	53	29	89	0.89	High	2.72	Moderate

The analysis within **Table 2** indicates that the macrobenthos community within the Ampekale Mangrove Area is predominantly dominated by the Gastropod class, with the *T. mauritsi* species emerging as the most prevalent. Additionally, within the Crustacea class, *Uca* sp. dominates the landscape, while *N. verrilli* represents the Bivalvia class. This observation mirrors the findings of Murniasih et al. (2022) in the Kali Ijo Estuary, where Gastropods of the genus *Telecopium* and Crustaceans of the *Uca* sp. and *Scylla* sp. types were commonly identified.

Considering the calculation of abundance, it is notable that the abundance of Macrobenthos across most stations is generally categorized as high, except for stations 8, 10, 11, 13, and 14. Moreover, when evaluating dominant diversity, most stations exhibit moderate diversity, with stations 1 (high) and 6 (low) being exceptions. The observed variations in Macrobenthos abundance within mangrove areas can be attributed to distinct environmental conditions and varying station locations, which substantially influence the abundance levels of mangrove fauna (Kusuma et al. 2020).

The composition of biota species acquired is intricately linked to the density and thickness of mangroves. Denser and thicker mangrove cover increases biota density (Abubakar et al. 2022). The distinction in macrobenthos fauna abundance between sparse-medium and medium-dense density is more pronounced at the latter. This discrepancy is primarily due to the more substantial difference between sparse and medium mangrove density, leading to distinctive physical and chemical environmental conditions. Taqwa et al. (2013) attribute this distinction to litter production. Elevated mangrove density leads to increased litter formation, thereby fostering the generation of detritus and nutrients. Detritus nourishes macrobenthos, consequently supporting the proliferation of benthos fauna within the ecosystem. Similarly, nutrients derived from detritus fertilize benthic algae, serving as a food source for macrobenthos.

Stations 1, 2, 4, and 15, situated at river estuaries with high mangrove density, exhibit concurrent high macrobenthos abundance. This alignment suggests that areas with thick mangroves show stable ecosystem conditions with abundant macrobenthos. This finding resonates with the assertions of Hutama et al. (2019), stating that communities that have high biodiversity correspond to stable ecosystems, while ecosystems characterized by lower biodiversity, such as station 6, show lower stability. Therefore, it is necessary to ensure that mangrove density is maintained and made dense, considering that mangroves are a place for various fauna to live.

4. Conclusions

Mangrove ecosystems in the Ampekale are mainly categorized as dense, indicating healthy conditions. This conclusion is reinforced by the abundant and diverse macrobenthos species inhabiting this area. Our study used RS with NDVI analysis on Sentinel-2A images and GIS for data representation, which was complemented by careful field surveys. Using RS to measure mangrove density makes the process easier and more efficient. The use of geospatial methodologies, such as RS and GIS, facilitated precise monitoring of mangrove density and seamless integration of macrobenthos observations from sample points in the field. Notably, mangrove density significantly influences litter production, which turns into detritus- an important food source for macrobenthos. A comprehensive analysis of mangrove density and macrobenthos diversity is crucial in evaluating the health of mangrove ecosystems. This assessment is essential to support the sustainable management of mangrove ecosystems. This research is an effort to monitor mangrove ecosystems in Ampekale Village through geospatial methodologies that include remote sensing.

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