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MORALITY BEFORE KNOWLEDGE

Remote sensing analysis of base cover of the water in Bontosua Island, Pangkajene and Islands Regency

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ABSTRACT

Background: Among the Spermonde Archipelago is strategically important and predominantly medieval islands is Bontosua Island. In order to preserve the health and vitality of the ecosystems, the local communities on this island actively participate in environmental conservation. With the help of this study, the bottom cover of the waters surrounding Bontosua Island, Pangkajene Regency, and the archipelago will be mapped, and the relationships between various types of bottom cover will be ascertained. **Methods:** From March to September of 2022, the study was carried out. Images from the Sentinel-2A satellite were obtained on July 29, 2021. Using the Lyzenga procedure and the values ki/kj = 0.876875437 and a = -0.280796034, water column adjustment was carried out. The Unsupervised Classification approach was used to classify the images, and the Rapid Reef Assessment (RRA) method was used to verify the bottom water cover in the field. **Findings:** With a total area of 69.42 hectares, the results revealed seven dominating objects: deep sea, sand, dead coral, dead coral with algae, and coral debris (11.17 ha), living coral (17.32 ha), broken coral (12.73 ha), sand (4.43 ha), seagrass (12.61 ha), and dead coral with algae (11.16 ha). **Conclusion:** In the waters surrounding Bontosua Island, live coral constituted the greatest portion of the bottom cover, accounting for 25% of the total, while sand made up the least amount, just 6%. **Novelty/Originality of this Study:** The study on Bontosua Island's water bottom cover is novel due to its use of Sentinel-2A satellite imagery combined with the Lyzenga procedure and Unsupervised Classification approach, offering high-resolution mapping of underwater ecosystems. Additionally, the study's comprehensive classification and verification process through RRA provides detailed insights into the distribution and health of various bottom cover types, contributing to enhanced environmental conservation efforts in the Spermonde Archipelago.

KEYWORDS: sentinel-2A; bottom coverage; unsupervised classification.

1. Introduction

Coral reefs function as the main ecological habitat that supports the survival of fish. They provide essential facilities for spawning, larval growth, and adulthood, as well as supplying food and oxygen. The need for fish in Indonesia is very important because it supports the domestic market for its population. Geographically, all provinces in Indonesia have 100% coastal areas that are utilized for activities in the marine and fisheries sector. Disturbance of coral reefs can cause a decline in coral fish populations. Loss of coral can impact fish over a short period of time, for example several weeks or months, by reducing

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the activity and physiological condition of reef fish. Over a longer period of time, for example several years, there can be a decline in fish abundance and diversity (Rani et al., 2019).

The Spermonde Islands are one of the important locations for the distribution of coral reefs, having 78 genera and subgenera including 262 species. Around 80-87% of these species inhabit the outer reef areas. However, the diversity and cover of coral reefs in this area has decreased over the last twelve years (Nurdin et al., 2015). The area of this area is around 150 square kilometers, and the current problem is quite serious damage due to uncontrolled use by individuals or local communities. Destructive fishing practices, such as bombing and poisoning, account for 40% of destructive fishing revenues in the Spermonde Islands (Wahyulfatwatul et al., 2017).

Conserving these important ecosystems requires concerted efforts to mitigate human impacts and encourage sustainable practices (Nicholson et al., 2015; Wang et al., 2024; Cook et al., 2021). Restoration projects and protective regulations are critical to reversing the damage and preserving remaining coral reefs (Razak et al., 2022; Boström-Einarsson et al., 2020; Toth et al., 2023). Educating local communities about the importance of coral reefs and involving them in conservation efforts can also play an important role in ensuring the sustainability of these ecosystems. In addition, ongoing research and monitoring are essential to understand changes occurring in the health of coral reefs and to develop effective strategies for their protection (Watt-Pringle et al., 2024; Sebastian et al., 2024; Trialfhianty et al., 2017; Ochieng et al., 2024).

Based on field observations, the seabed composition around the Spermonde Archipelago waters consists of live coral, dead coral overgrown with algae, coral fragments, and sand partially covered with algae. Coral reefs serve as an example to observe the influence of habitat complexity on the diversity and abundance of associated organisms. The heterogeneity structure and the degree of irregularity of the structural elements form the topographic contours of a location. A high structural complexity of the seabed can be used to estimate high species abundance. Corals are hollow-bodied animals classified within the phylum Coelenterata. Broadly, animals from the class Anthozoa are divided into two groups: those that produce calcium carbonate skeletons (hermatypic) and those that do not (ahermatypic). Generally, corals capable of forming reefs have a symbiotic relationship with zooxanthellae, which are single-celled algae. Zooxanthellae located in the endodermal layer can produce 10,000g of CaCO3 per square meter per year. The presence of zooxanthellae, which are algae from the Dinoflagellate group, is crucial for hermatypic corals. Zooxanthellae also play a role in providing 85% of the nutritional needs of the coral through the products of photosynthesis (Putnam et al., 2017).

In general, it is known that hermatypic corals with branching growth forms, such as Acropora, Seriatopora, Stylophora, Millepora, and Pocillopora, are more susceptible to various stresses, including bleaching events (Carrasco-Pena et al., 2020; Razak et al., 2020; Vessaz et al., 2022). These corals tend to have thinner tissue layers, making their zooxanthellae more susceptible to environmental stress. The symbiotic relationship between corals and zooxanthellae is essential for coral health, as these microalgae provide essential nutrients through photosynthesis. However, when environmental conditions deteriorate, such as during periods of increased water temperatures or high levels of pollutants, the ability of zooxanthellae to photosynthesize effectively decreases. This vulnerability can lead to higher mortality rates in branching corals during adverse conditions, as the loss of zooxanthellae results in a significant decrease in energy reserves, making the coral less able to withstand stress. Additionally, the increased vulnerability of these coral species could disrupt the entire coral reef ecosystem, as they are critical for maintaining structural complexity and biodiversity.

In contrast, many studies have observed that large corals with relatively slow growth rates (such as Porites, Favia, Favites, Goniastrea, Astreopora, and Turbinaria) show greater resilience to environmental stress. This thicker layer of coral tissue provides better protection for the zooxanthellae, which are critical to the nutrition and overall health of the coral. This protective advantage allows large corals to withstand higher levels of stress, such as temperature fluctuations, pollution, and physical damage, thereby contributing to longer lifespan and stability of reef ecosystems (Edmunds et al., 2014).

The geomorphology of coral reef ecosystems categorizes them into three main types, namely fringing reefs, barrier reefs, and atolls. Fringing coral reefs grow directly along coastlines and extend out to sea, often serving as important coastal buffers. The barrier reef is separated from the coastline by a lagoon, creating its own marine environment that supports a diverse range of marine life. Atolls are ring-shaped coral reefs that surround lagoons, usually formed by the sinking of volcanic islands. These unique formations contribute to the richness and resilience of the marine environment, supporting a high diversity and abundance of species.

Bontosua Island is located at the midpoint of the Coral Triangle zone within the Spermonde Archipelago, a region renowned for its rich biodiversity and significant marine resources. This geographical position makes it an epicenter for observing coral reefs located in the central region of the Coral Triangle, where a variety of coral species thrive alongside a diverse range of marine life. Recognizing the ecological importance of this area, the HOPE program was launched in the waters of Bontosua Island by SHIBA, with the primary goal of conserving coral reefs that are under serious threat from both global climate change and anthropogenic activities. These threats include rising sea temperatures, ocean acidification, pollution, and overfishing, which collectively endanger the health and health of coral ecosystems. To address these challenges, coral transplantation has been implemented as an important strategy to restore the island's coral ecosystem. This process involves carefully selecting healthy coral fragments from donor sites and transplanting them to degraded areas, which encourages growth and increases biodiversity. These restoration efforts aim to create a fertile marine environment where various fish species, including turtles, sharks and rays, can return to the rehabilitation area.

The Sentinel-2A satellite offers spatial resolution for mapping coastal areas. Its images, accessible to the public for free with a spatial resolution of 10 x 10 meters, provide an advantage in analyzing captured images compared to the 30 x 30 meter resolution of Landsat, which may introduce more significant bias in research. The Sentinel-2A satellite also features advanced atmospheric and geometric corrections, making it easier for researchers to analyze the imagery (European Space Agency, 2015). Sentinel-2A is commonly used for coastal area mapping.

Bontosua Island is the midpoint of the Coral Triangle, located in the Spermonde Archipelago. This location serves as an epicenter for observing coral reefs situated in the center of the world's coral triangle. Reef fish permanently reside and feed in coral reef areas, therefore damage or destruction of coral reefs will result in the loss of habitat for reef fish. As fish that depend on coral reefs, damage or deterioration of coral reef conditions will affect the diversity and abundance of reef fish (Rani et al., 2019).

A study conducted by Nirwan et al. (2017) on coral bleaching in the Liukang Loe Island coral reefs in May 2016 found that coral cover was about 13.12% at a depth of 10 meters or about 6-7% at a depth of 3 meters. These conditions align with research by Rani et al. (2019) at the same location, which showed that changes in coral reef conditions caused by natural events or human actions can alter the structure of the associated biota. The study results indicated that the value of live coral cover influences the richness of reef fish species but does not affect their abundance. Groups with lower live coral cover have fewer reef fish species than groups with higher coral cover.

Healthy coral reefs have a high quantity of food, which positively impacts fish diversity because these reefs provide better protection for many biota and offer a safe place for reproduction and nurturing of offspring (D'Angelo & Wiedenmann, 2014; Mellin et al., 2022). Complex and healthy coral reefs maximize diversity and spatial extent during the reproduction process by providing the right environment for reproduction and fish larvae placement. The abundance and diversity of reef fish are influenced by many factors, including live or dead coral cover. These factors include microhabitat diversity or habitat complexity, rugosity levels, and the presence or proximity to surrounding ecosystems such as seagrass beds and mangroves (Rani et al., 2019). Therefore, research related to mapping shallow water areas using the Sentinel-2A satellite is necessary.

2. Methods

This research was conducted from February to March 2022 and included several essential stages, namely preparation, initial observation, station determination, field data collection, data processing, and the preparation of the research report. During the preparation phase, a comprehensive review of existing literature and relevant studies was undertaken to inform the research design and methodology. Initial observations were made to gain insight into the site's conditions and to identify key areas of interest for further investigation. Subsequently, specific stations were determined based on factors such as water depth, coral coverage, and ecological significance. Field data collection involved a series of systematic surveys and assessments aimed at gathering quantitative and qualitative data on coral health, biodiversity, and environmental parameters. This phase was crucial in ensuring that the data collected would provide a robust foundation for analysis. Following the fieldwork, data processing was carried out to analyze the collected information using appropriate statistical methods and software tools. This analysis helped in understanding the dynamics of the coral ecosystems in the study area. Finally, the research report was prepared, summarizing the findings, methodologies, and implications of the study. The research was carried out on Bontosua Island, which is located in the Liukang Tupabbiring Selatan District, Pangkajene and Islands Regency, an area noted for its rich marine biodiversity and significance within the Coral Triangle. Figure 1 illustrates the geographical location of Bontosua Island, providing context for the study's relevance and scope.

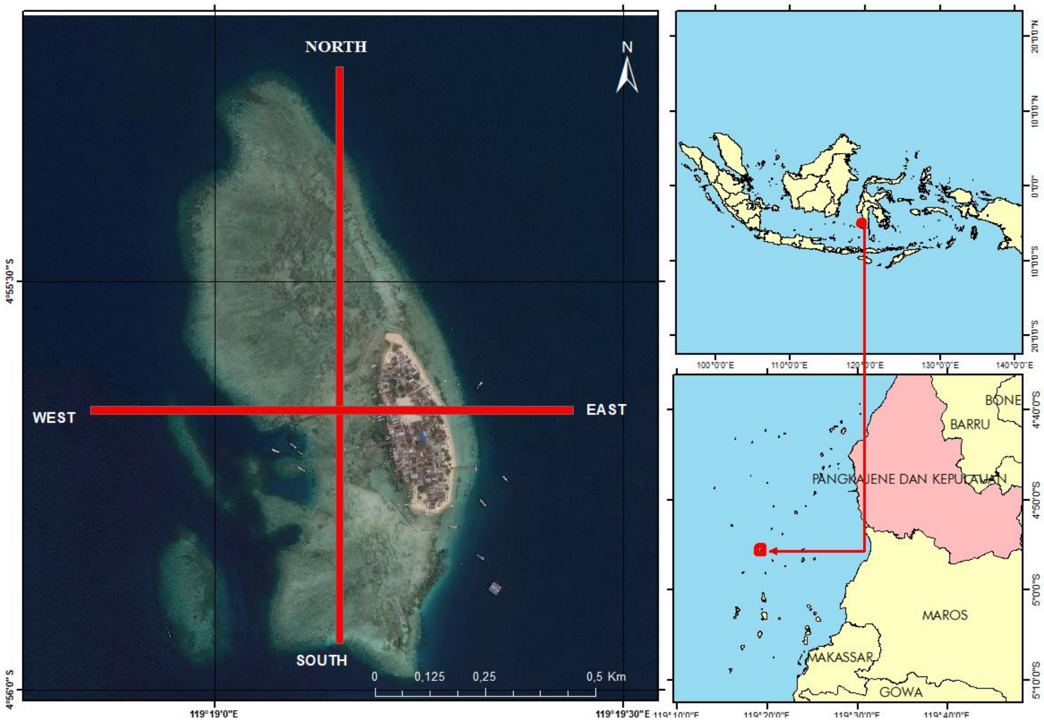

Fig. 1. Bontosua Island, Pangkajene and Islands Regency

Sentinel-2A satellite images, which can be downloaded from https://scihub.copernicus.eu, were used to map the shallow water habitats around Bontosua Island. The Sentinel-2A satellite, developed by the European Space Agency (ESA) for Earth observation, provides free data. The Sentinel-2A satellite sensor has a spatial resolution of 10x10 meters and a radiometric resolution of 12 bits. Additionally, it has a temporal resolution of 10 days for a single satellite and 5 days for a combined constellation.

Since the level 2 Sentinel-2A images have already been geometrically corrected, the images used in this study did not require further geometric correction (European Space Agency, 2015).

The first step in satellite image processing is cropping the satellite images. Following this, the separation of land and sea is carried out using the Normalized Difference Water Index (NDWI) method (Figure 3). This method effectively distinguishes water bodies from land areas, facilitating more accurate analyses of the coastal environment.

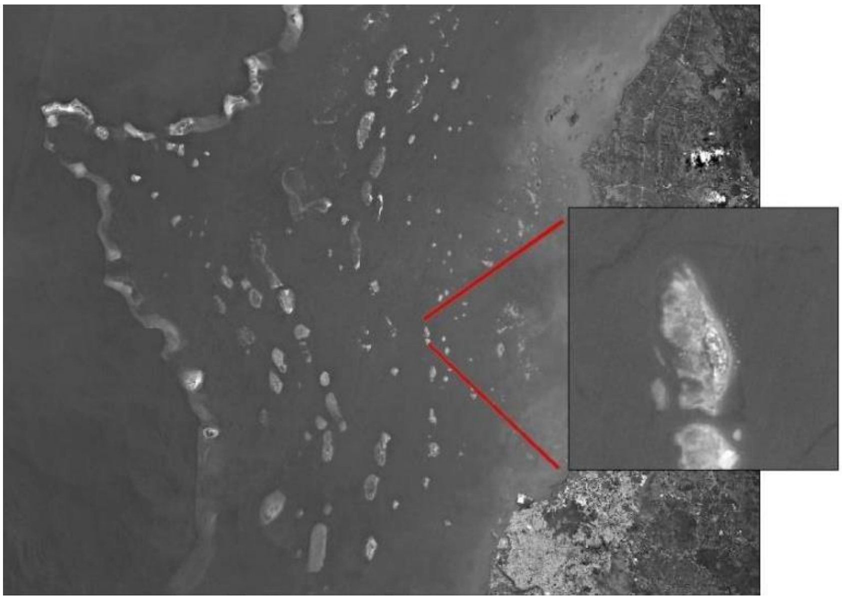

Fig. 3. Cropping the satellite images

In the sentinel-2A satellite image, Green is band 3, while NIM is Banda Near Independent or band 8. The purpose of this step is to eliminate irrelevant land areas and include only the shallow water regions in the satellite image analysis. After the masking process, the satellite image processing proceeds through several stages. First, band composites are used to combine information from different image bands into a single composite. The aim is to produce an RGB (Red, Green, and Blue) representation that accurately reflects the natural environment. For this study, true color composites were used. This method is recommended for identifying shallow water habitats due to its clear water penetration capability (Badan Informasi Geospasial, 2014).

Water column correction is performed to gather accurate data on subsurface objects without the influence of depth, turbidity, or surface water movement. This is achieved using the Depth Invariant Index, derived from the Lyzenga algorithm (Lyzenga, 1981), which combines visible light bands to create a new image. The satellite images are then classified using an unsupervised classification method. Initially, images are classified based on the reflectance values of each shallow water object without requiring prior training samples. However, for further classification, such as distinguishing the four classes of shallow water habitats in this study (live coral, dead coral, seagrass, and sand), the Maximum Likelihood Classification (MLC) supervised classification method is used. MLC arranges pixel values according to their probability of belonging to a specific class based on training pixel samples (Badan Informasi Geospasial, 2014).

Data collection for assessing the benthic cover of Bontosua's island waters was conducted using the Reef Rapid Assessment (RRA) method. This involved selecting pixel-labeled areas on different unsupervised maps to identify the benthic substrate cover, providing a percentage of benthic cover based on the RRA method through substrate classification. The classification ranged from the shoreline to the reef slope at depths of 0-15 meters along Bontosua island (English, 1999). The classification was divided into six main classes: sand, live coral, dead coral, rubble, algae, and mix (combination). If multiple classes were found in one location, additional classes could be added as each island's characteristics are unique (Febrianto et al., 2021; Nurdin, 2018). The benthic cover was divided into four cardinal directions to view the island's composition more specifically based on the research map (Figure 4).

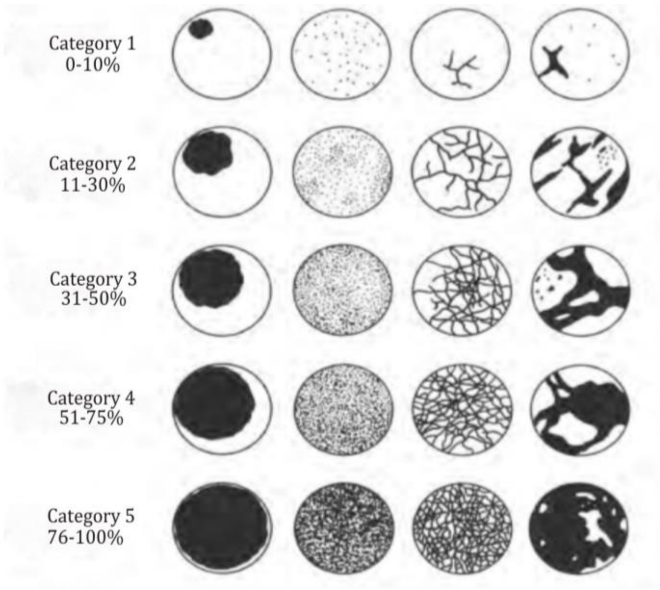

Fig. 4. The benthic cover

Providing an overview of the shallow water data for the island is essential to interpret each water class based on image label testing and ground truth (LIPI, 2018). This overview allows for accurate classification of the different water categories and ensures a better understanding of the ecological dynamics taking place. Equation 1 illustrates the formula used to calculate the percentage coverage of each category, which is determined by the number of points in that category relative to the total number of random points sampled.

$$Category\ Coverage\ Percentage = \frac{Number\ of\ points\ in\ the\ category}{Total\ number\ of\ random\ points} \times 100 \quad \text{(Eq. 1)}$$

2.1 NDWI and Lyzenga equation

NDWI is used for masking satellite images by separating the island's land from shallow waters to reduce bias in image data analysis. This separation is crucial for ensuring that the analysis accurately reflects the characteristics of the water bodies. The NDWI equation can be seen in Equation 2, which outlines the specific calculation method used in this process (McFeeters, 2013).

$$NDWI = (Green-NIR) / (Green+NIR) \quad \text{(Eq. 2)}$$

Meanwhile, Lyzenga equation aims to interpret water depth and reduce the bias from sea surface reflections, allowing for accurate analysis of the water column (Equation 3). *Li* is reflectance value of band i (shorter wavelength channel); *Lj* is Reflectance value of band j (longer wavelength channel); σii is variance of band i (shorter wavelength channel); σjj is variance of band j (longer wavelength channel); σij is covariance of bands i and j; and *ki/kj* is Ratio of attenuation coefficients of bands i and j.

$$DIIij = In(Li) - \left[\left(\frac{ki}{kj}\right)\right] In(Lj) \quad \text{(Eq. 3)}$$

$$\frac{ki}{kj} = a + \sqrt{a^2 + 1}$$

$$a = \frac{\sigma ii - \sigma jj}{2 \times \sigma ij}$$

3. Results and Discussion

Figures 5 (A and B) illustrate fundamental differences and the clustering of clusters extracted from 30 clusters into 7 main clusters. Figure 6 depicts shallow water analysis where clustering has not been applied yet, showing that deep-sea objects have the highest reflectance values in the blue channel with a wavelength of 490 nm. This is because wavelengths of green, red, and infrared are predominantly absorbed by the deep sea, resulting in a darker appearance. Meanwhile, other shallow water substrates such as live coral, dead coral with algae, sand, coral rubble, seagrass, and mixed habitats (a combination class of live coral, sand, coral rubble, and dead coral with algae) exhibit higher reflectance values in the green channel. This is due to these objects reflecting more green wavelengths and absorbing blue and red wavelengths. Nurdin (2018) explains that plants tend to reflect green colors more because they contain chlorophyll-a and chlorophyll-b pigments, which absorb other wavelengths.

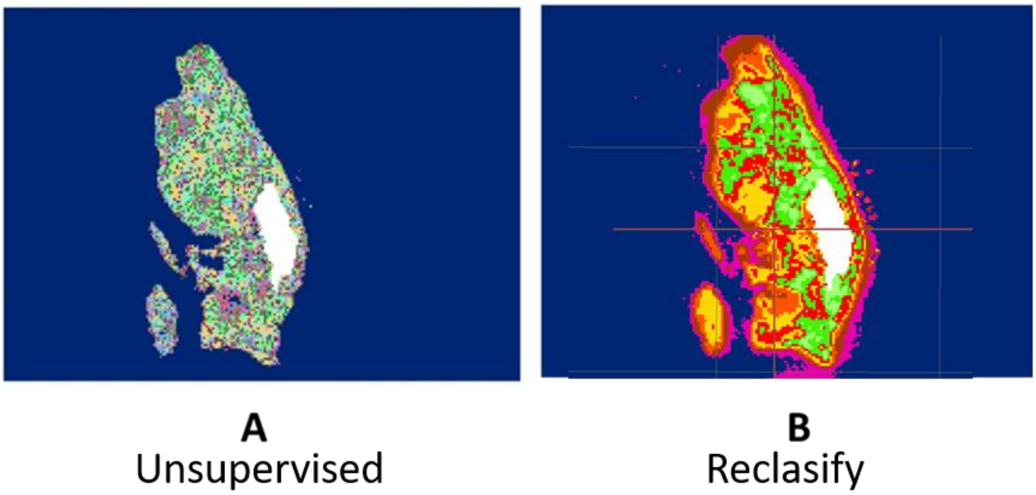

Fig. 5. Unsupervised and image reclassification

The ground truth verification results indicate several dominant objects representing each ground truth point, consisting of very good coral, good coral, good coral, coral rubble, coral with sand, and seagrass. The ground truth data is used as a reference in the accuracy testing process. Based on the field verification results at 130 points scattered across Bontosua island (Figure 6), it shows the distribution of point sampling to interpret the waters of Bontosua island.

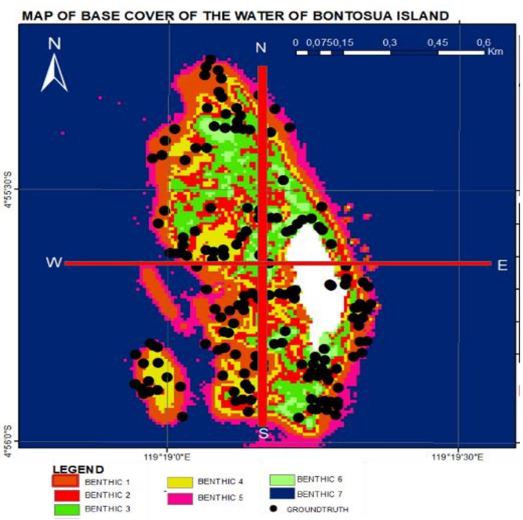

Fig. 6. Field verification points of shallow water substrate

In Figure 7, there are 162 Ground Truth points (field verification) conducted to demonstrate the brighter appearance of live coral objects compared to coral rubble objects. Objects approaching white reflect large electromagnetic waves. Therefore, it is assumed that live coral objects have higher reflectance compared to spectral values of coral rubble.

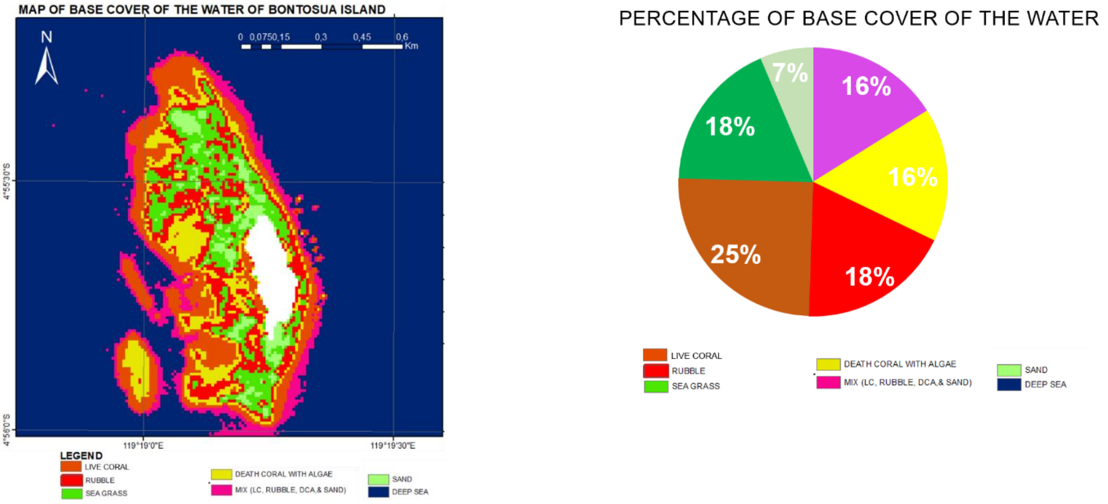

Fig. 7. Map of seabed cover in Bontosua island waters

In Figure 8, the map of seabed cover in Bontosua island waters shows that the most dominant seabed cover is located to the west and the least in the east. This is due to the extensive shallow waters to the west of the island, while the eastern part of the island has steeper contours used as anchorage spots for ships. The influence of contours and oceanographic parameters of the Spermonde Islands, as described by Rasyid (2014), indicates that islands in this region tend to have deeper eastern sides due to the influence of the two seasons and the Indonesian Throughflow passing through the Sulawesi Sea, consistent with conditions at Pulau Bontosua. Bontosua island has many large docks and breakwaters, resulting in numerous large and small vessels anchoring there, causing damage to coral reefs. These activities lead to coral reef damage as fishermen and visitors often anchor their boats on coral reefs or throw their anchors, damaging coral colonies.

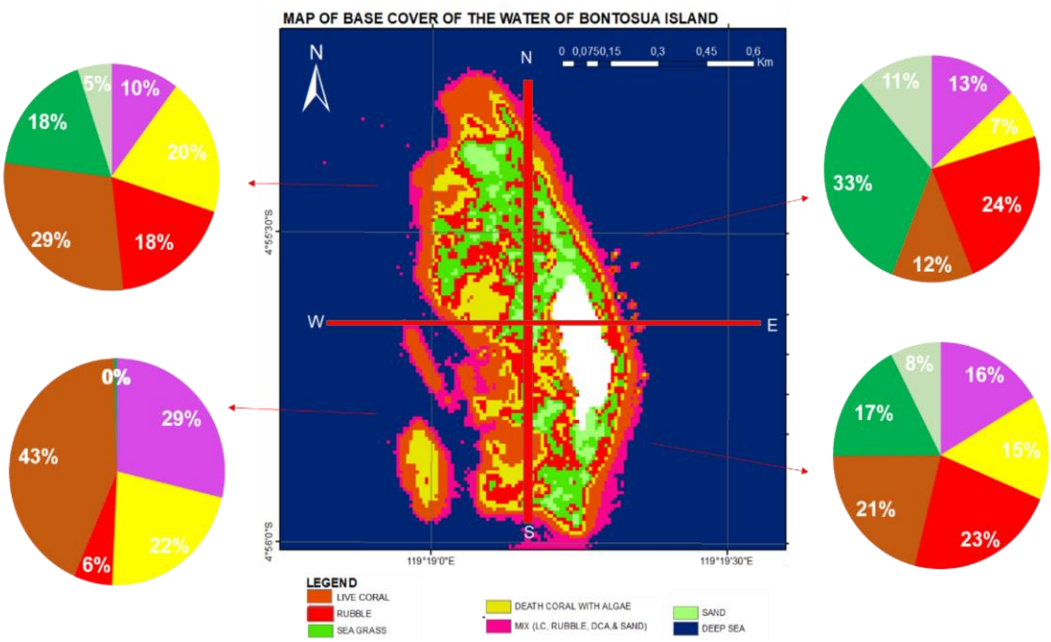

Fig. 8. Map of bottom coverage based on island directions

The classification and field surveys in the shallow water areas of Bontosua island divide the region into six categories of seabed coverage, including sand, seagrass, coral rubble, dead coral with algae, live coral, and mixed (live coral, dead coral, sand, and rubble). The total area of Bontosua island is 69.42 hectares, where live coral covers the largest area at 25% (17.32 hectares), while the smallest area is sand at 6% (4.43 hectares), seagrass covers 18% (12.61 hectares), coral rubble covers 18% (12.73 hectares), dead coral with algae covers 16% (11.16 hectares), and mixed coverage (live coral, rubble, dead coral with algae, & sand) covers 16% (11.17 hectares).

The largest percentage of shallow water area in Bontosua island is live coral at 25%, and the smallest is sand at 6%. The table indicates varying trends in the area of seabed coverage. Live coral covers the largest area among the five other regions, totaling 17.32 hectares. The smallest area is in the sand region, covering 4.43 hectares. Detailed types and areas of seabed coverage, divided from east to south, reveal that coral rubble covers the largest area at 23% (4.54 hectares), while sand covers the smallest area at 8% (1.53 hectares). Other areas include live coral at 21% (4.23 hectares), mixed coverage at 17% (3.32 hectares), seagrass at 17% (3.52 hectares), and dead coral with algae at 15% (2.99 hectares). Further division from north to east shows that seagrass covers the largest area at 33% (5.32 hectares), and dead coral with algae covers the smallest area at 7% (1.16 hectares). Other areas include coral rubble at 23% (3.81 hectares), mixed coverage at 13% (2.16 hectares), live coral at 12% (2 hectares), and sand at 11% (1.84 hectares) (Table 1).

Dividing from south to west reveals that live coral covers the largest area at 43% (5.34 hectares), and sand covers the smallest area at 0.05 hectares. Other areas include mixed coverage at 29% (3.56 hectares), dead coral with algae at 22% (2.73 hectares), and coral rubble at 6% (0.72 hectares). Meanwhile, no identification of seabed was found for sand. Finally, dividing from east to south reveals that live coral covers the largest area at 29% (5.93 hectares), and sand covers the smallest area at 5% (1.05 hectares). Other areas include dead coral with algae at 20% (4.07 hectares), coral rubble at 18% (3.76 hectares), seagrass at 18% (3.68 hectares), and mixed coverage at 10% (2.11 hectares) (Table 1).

Table 1. Types and area of shallow water coverage on Bontosua Island

No	Substrat	North to East		East to South		South to West		West to North		Area (ha)	Persent (%)
		ha	%	ha	%	ha	%	ha	%		
1	Mix	2.16	13	3.32	17	3.56	29	2.11	10	11.17	16
2	DCA	1.16	7	2.99	15	2.73	22	4.07	20	11.16	16
3	RB	3.81	23	4.54	23	0.72	6	3.76	18	12.73	18
4	LC	2.00	12	4.23	21	5.34	43	5.93	29	17.32	25
5	SG	5.32	33	3.52	17	0.05	0	3.68	18	12.61	18
6	S	1.84	11	1.53	8	0	0	1.05	5	4.43	6
	Total	16.30	100	20.13	100	12.39	100	20.60	100	69.42	100

*Mix = Mix (LC, DCA, S); DCA = Dead coral withl algae; RB = Rubble; LC = Live Coral; SG = Sea Grass; S= Sand

Table 1 provides a clear picture of the composition of the seabed around Bontosua Island, where the highest percentage is found in live coral, reaching 25% or equivalent to 17.32 hectares of the total area studied. The dominance of coral life in these shallow waters is inseparable from the active intervention of the community in maintaining coral reef habitats, especially in marine protected areas (MPAs). The local community has taken the initiative to carry out awareness programs on coral reef conservation, which play a significant role in increasing awareness of the values of the ecosystem they have. On the other hand, the lowest percentage of the composition of the seabed on Bontosua Island is sand, which only reaches 10% or 4.43 hectares. According to Sawayama et al. (2015), sand in this area is described as a weathering substrate originating from fragments of living and dead coral, as well as from the decomposition process of limestone facilitated by waves and ocean currents. This weathering process produces fine particles that contribute to the formation of sand substrates, which have different reflectance compared to other substrates, such as living coral or seagrass. With the conservation efforts carried out, it is hoped that the coral ecosystem on Bontosua Island can continue to be maintained and provide ecological, social and economic benefits for the surrounding community.

Live coral (25%), as the seabed environment, is inhabited by dominant coral biota containing calcium carbonate (CaCO3), structured in clusters mainly from the Scleractinia order. The appearance of live coral in sentinel images from channels 2, 3, and 4 shows a dark bluish coloration, which can be attributed to the specific light absorption and reflection characteristics of the coral structure. The extensive coverage of live coral is influenced by the water column in spectral reflection processes, as the sensor detects objects around live coral as part of it, leading to the potential for misclassification if not properly accounted for. Unsupervised classification results without the Lyzenga algorithm show no detection of coral rubble, indicating a significant oversight in accurately capturing the complexity of the seabed environment. Kartika's research (2019) indicates that classification without applying the Lyzenga algorithm would result in overly extensive sand classification due to spectral reflection influences in the water column, which can cause the sensor to inaccurately detect surrounding objects as sand. Therefore, the application of the Lyzenga algorithm in imagery is necessary to mitigate water column disturbances, thereby improving the quality and appearance of objects in the images. This enhancement is crucial not only for accurate classification but also for effective marine management and conservation efforts, as it allows for better understanding of coral health and the overall marine ecosystem dynamics.

Classes of dead coral with algae, coral rubble, and live coral exhibit similarities in spectral values. This is because objects such as dead coral with algae, coral rubble, and live coral have a brownish coloration, which can lead to challenges in differentiating between these classes during analysis. When identifying these types, broken live coral or coral fragments covered with algae appear brown, making it difficult to distinguish them from each other. Their reflectance values tend to be high at a wavelength of 560 nm (green channel), which is characteristic of these brownish hues. Nurdin et al. (2018) state that dead coral, live coral, and coral rubble exhibit similar reflectance, with live coral and coral rubble showing spectral reflectance peaks at a wavelength of 679 nm using hyperspectral analysis. This overlapping reflectance can complicate the interpretation of satellite images and necessitates advanced processing techniques for accurate classification. Furthermore, over time, coral fragments covered by rapidly growing algae become significantly darker compared to coral rubble, which can alter their spectral signatures. This darkening process highlights the importance of continuous monitoring and assessment to understand the ecological changes affecting coral reef health and resilience in response to environmental stressors.

Seagrass, which does not form a group with other objects, does not show spectral similarities despite its habitat on the seabed. Seagrass is a species of photosynthetic plant with a different pigment structure that allows it to capture light for photosynthesis (Kartika, 2019). This unique characteristic produces a different spectral signature compared to corals and other benthic organisms. Suwandana et al. (2012) studied the differences in spectral reflectance of seagrass compared to other objects measured by hyperspectral sensors, which revealed a maximum spectral reflectance range in the visible spectrum between 500 and 690 nm, with a peak reflectance at 550 nm. This peak indicates that seagrass reflects light more effectively in this wavelength, which can be important to distinguish it from the surrounding substrate in satellite imagery. Furthermore, the absence of grouping in seagrass improves its detectability in remote sensing applications, allowing for more precise mapping of seagrass beds in coastal environments. Understanding these spectral properties is important for monitoring the health and distribution of seagrasses, which play a critical role in coastal ecosystems by providing habitat, stabilizing sediments, and improving water quality. These insights can inform conservation strategies aimed at preserving seagrass habitats, especially in areas facing threats from human activities and climate change.

4. Conclusions

This study successfully identified the entire bottom cover of Bontosua Island waters by dividing it into six classes using Sentinel-2A satellite imagery technology. These classes include mixed classes, consisting of live coral, dead coral with algae, sand, and coral fragments, as well as separate classes for live coral, dead coral with algae, coral fragments, sand, and seagrass. The total area of bottom cover of the waters analyzed reached 69.42 hectares, where the percentage of live coral showed the highest value, which was 25% or equivalent to 17.32 hectares of the total bottom cover of the waters.

The results of this study provide important insights into the condition of the coral ecosystem on Bontosua Island. The excess number of live coral compared to other classes reflects the health of the existing ecosystem and indicates that this area can still be a productive habitat for various marine species. However, the presence of other classes such as dead coral containing algae and coral debris indicates pressure on the ecosystem, which can be caused by environmental factors or human activities.

Therefore, this study implies that the implementation of targeted conservation strategies is very important to protect the living coral ecosystem in the waters of Bontosua Island. These efforts are not only to maintain biodiversity, but also to increase the resilience of the ecosystem to environmental changes and other threats that can affect the survival of coral reefs. With a better understanding of the distribution of bottom cover, it is hoped that marine resource management and conservation policies can be formulated more effectively, to ensure that this vital ecosystem can continue to function well and provide benefits to the community and the surrounding environment.

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Author Contribution
A.H.N., N.N., A.H., A.F., and C.R. conceived the study, carried out all research activities, analyzed the data, wrote the manuscript, and were responsible for the final content. The authors approved the final version and agreed to be accountable for all aspects of the work.

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