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CORAL REEF DISTRIBUTION MAPPING CASE STUDY OF SETAN ISLAND WATERS, WEST SUMATRA

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ABSTRACT

The research was conducted in May 2023 in Setan Island, West Sumatra. The study aimed to map the distribution of coral reefs, test the accuracy of the resulting map, and determine the condition of coral reef cover on Setan Island. The methods used are remote sensing methods using Sentinel-2 satellite imagery and field survey methods to validate the distribution of coral reefs resulting from image data processing (Groundcheck) and to observe the condition of coral reefs using the Underwater Photo Transect (UPT) method. Determination of sampling locations to ground check the distribution of coral reefs using a Stratified random sampling method while determining sampling locations for observations of coral reef cover using a purposive sampling method. The study results obtained a coral reef distribution map with a reef distribution area of 13.18 ha or 47.55% of the total shallow water area. The accuracy test found an accuracy value of 80% with a kappa coefficient 0.7, where the category is good and the level of trust is moderate. The condition of coral reef cover based on live corals in the waters of Setan Island is in the Fair and Poor categories. Percentages range from 0.33% to 31.36%. The dominating lifeform types are coral massive and coral submassive.

Keywords: Remote sensing, Mapping, Coral Reef, Setan Island

1. INTRODUCTION

As an archipelago, Indonesia has around 17,500 islands with a coastline of 95,181 km[1]. Many coastal and marine ecosystems such as coral reefs, are along its coasts and waters. Coral reefs are ecosystems formed by lime-producing marine biota, especially coral animals consisting of polyps and skeletons[2]. This ecosystem plays an important role economically and ecologically, one of which is as a habitat and life support for coastal and marine biota. Coral reef ecosystems are critical and need to be preserved. However, the vast territory of Indonesia is a challenge. The utilization of remote sensing technology facilitates this effort. This technique is an effective and less expensive way to map and monitor shallow water habitats, especially coral reefs. Information obtained from remote sensing includes the spatial and temporal distribution of coral reefs through satellite imagery.

The satellite imagery used is Sentinel-2, which is of good quality and free access. Mastu et al.[3] explain that Sentinel-2 satellite imagery is a new alternative to providing earth surface information. In addition to being readily available and accessible, Sentinel-2 imagery offers image data quality with a better spatial resolution of 10x10 m^2/pixel. However, remote sensing technology has weaknesses in its application, namely in the form of disturbances that cause errors and lack of accuracy in reading the satellite image and the classification process. Therefore, an accuracy test is needed in its application to find out how many errors users make in the processing process and how accurate the resulting map is.

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Coral reefs are currently facing the threat of destruction. This threat of damage comes from various natural and anthropogenic factors. One of the coral reef ecosystems is located in the waters of Setan Island, West Sumatra. According to Khaidir et al.[4], the waters in West Sumatra are often found by fishermen who catch fish using explosives, so the coral reef ecosystem is threatened with damage. Setan Island is one of the Mandeh Tourism Object Area islands, Koto XI Tarusan District, Pesisir Selatan Regency, West Sumatra Province, with marine tourism potentials such as beach tourism, snorkeling, and diving. The tourism potential on Setan Island does not rule out the threat of coral reef damage.

According to Khaidir et al.[4], coral reefs in the waters of Setan Island are very vulnerable to disturbances that cause damage because the beach's contours are flat or flat, so visitors prefer it. Given the potential and threat of damage to the coral reef ecosystem, preserving it to remain intact and sustainable is necessary. This study aims to map the distribution of coral reefs, test the accuracy of the resulting map, and determine the condition of coral reef cover on Setan Island.

2. RESEARCH METHOD

Time and Place

The research was conducted in May 2023. The study area was in the waters of Setan Island, Koto XI Tarusan District, Pesisir Selatan Regency, West Sumatra Province. The research location is shown in Figure 1.

Figure 1. Maps of the locations and research stations

Method

This study used remote sensing and field survey methods. Remote sensing was conducted with Sentinel-2 satellite imagery, while field surveys were conducted through ground checks to validate the distribution of coral reefs from image data. Coral reef observations were performed using the Underwater Photo Transect (UPT) method, and water quality data were measured in situ. Ground check locations were selected using stratified random sampling, while coral cover observation locations used purposive sampling. The research procedure began with downloading Sentinel-2 imagery, processing data into tentative maps, doing ground checks, and analyzing the final results, as described in the flow chart in Figure 2.

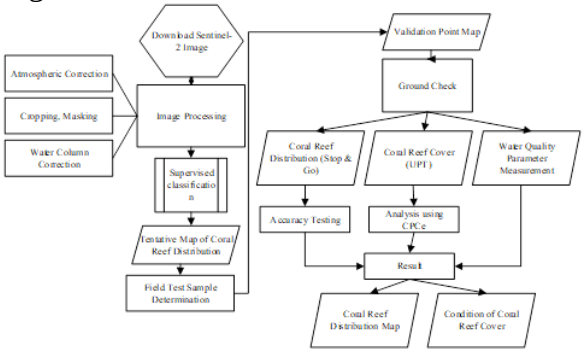


Figure 2. Flowchart of research procedure

This study's Sentinel-2 image data processing procedure begins with image download, followed by atmospheric

correction, cropping and masking processes, and water column correction. Data processing was carried out using ArcGIS 10.4 and SNAP applications. The data was downloaded from Sentinel-2 Level 1C Satellite Imagery through the website https://scihub.copernicus.eu/ with good quality and cloud-free imagery, taken in April 2023. The Rupa Bumi Indonesia shapefile map was downloaded from https://tanahair.indonesia.go.id /portal-web/download/region. Atmospheric correction clarifies objects in the image to facilitate subsequent processing[5].

Procedures

Before field validation, test sample points were determined using the stratified random sampling method. This method ensures that sample points are selected in a representative and proportional manner based on their class. According to Prayuda[6], the determination of sample points should consider natural conditions, such as water depth, reef flatness, spatial aspects, and factors of reef openness to wind, time efficiency, cost, and challenging terrain. Based on these considerations, 30 sample points were selected with 10 points per class.

Field validation was conducted based on a tentative map of coral reef distribution with 30 sample points. The process used a stop-and-go method, allowing researchers to move between points while monitoring underwater conditions. Researchers entered the water at each end and took photos to verify coral reef conditions. Each point was validated by comparing the class on the map with field conditions. The Avenza Maps smartphone app was used for navigation guidance, ensuring data collection went smoothly and according to plan.

The Underwater Photo Transect (UPT) method utilizes underwater digital camera technology and computer software. Coral cover data was collected by scuba diving, where photos were taken every 1 meter along a 50 m underwater transect parallel to the coast, resulting in 50 coral photos per site. Coral cover observations used a purposive sampling method that was considered representative. Four observation stations were selected based on cardinal directions, with data taken at 3 and 6 m depth.

Water quality data were collected in situ with four parameters: temperature, current velocity, salinity, and brightness. Measurements were taken at the water surface with three repetitions at each station, along with coral cover data collection. Coral cover data were analyzed using the CPCe (Coral et al. with Excel extension) application to obtain quantitative data[7]. Analysis was conducted on each photo frame by selecting 30 representative random points to estimate the percentage cover of categories and substrate. The percentage cover of each category was calculated for each photo frame.

$$\%\ \text{cover category} = \frac{Number\ of\ Category\ Points}{Number\ of\ Random\ Points} \times 100\%$$

After being analyzed, the cover will be determined based on the live coral category. According to Hadi et al.[2], the determination of coral condition categories based on the percentage of live coral cover is presented in Table 1.

Table 1. Coral reef condition categories based on live coral cover

Live coral cover (%)	Category
HC ≤25%	Poor
25% ≤ HC ≤ 50%	Fair
50% ≤ HC ≤ 75%	Good
HC > 75%	Excellent

The accuracy test measures the map's suitability to field conditions and their quality. Validation is done using an error matrix or confusion matrix, comparing image classification with field data, referring to the method of Green et al.[8]. The results include total accuracy, producer, user, and kappa analysis[9].

The results of the kappa coefficient calculation will then be matched with the level of suitability proposed by Landis & Koch[10], which is presented in Table 2.

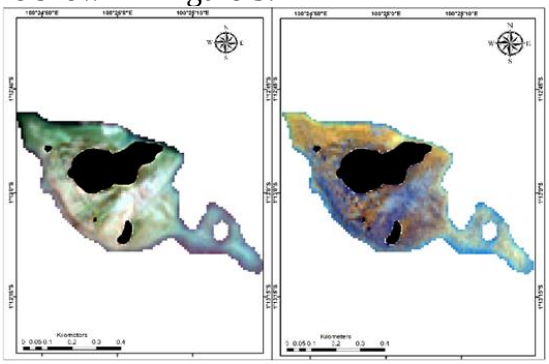
Table 3. Level of Conformity in kappa coefficient

Suitability Level	Trust Level
< 0,4	Low
0,5-0,8	Medium
> 0,8	High

3. RESULT AND DISCUSSION

Image Processing Results

Image processing to map the distribution of coral reefs was conducted using the SNAP application. The first step in this process is to extract the shape of the shallow water bottom with the Lyzenga[11] algorithm, known as Depth Invariance Indices (DII) or water column correction. The results of the satellite image processing are shown in Figure 3.

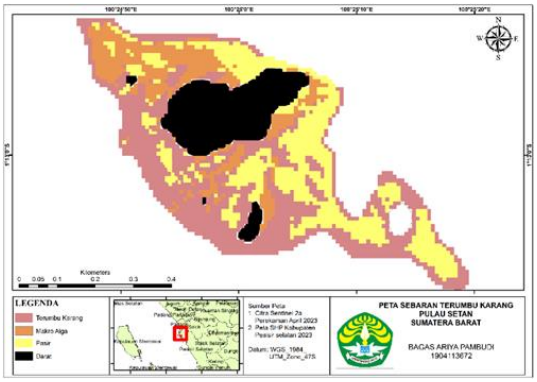


(a) (b)

Figure 3. Before the image is processed using the Lyzenga algorithm (a), Satellite image processing results (Water column correction) (b)

Coral Reef Distribution

Coral distribution maps were obtained from Sentinel-2 image processing using ArcGIS and SNAP software. In the research on Setan Island, processing was carried out with supervised classification using the maximum likelihood method on images that had been corrected using the Lyzenga algorithm. The classification consisted of Sand, Macroalgae, and Coral Reef. The area of each class was calculated using geometry after the raster image was converted into polygons. A map of the distribution of coral reefs on Setan Island is shown in Figure 3.



(a) (b)

Figure 3. Coral reef distribution map of Setan Island, West Sumatra

The coral reef distribution map results categorize several classes: coral, macroalgae, and sand. On the distribution map of Setan Island, these classes are shown in different colors: coral reefs are purple, macroalgae are brown, and sand is light yellow. The map is presented in Universal Transverse Mercator (UTM) projection with World Geodetic System 1984 (WGS-84) datum for horizontal control. The map colors and projections follow the 2011 Draft Indonesian National Standard-3 (RSNI) on mapping shallow marine habitats, part 1: coral reef and seagrass mapping. In this standard, coral reefs are colored purple (R:214; G:133; B:137), macroalgae brown (R:234; G:150; B:80), and sand yellow (R:255; G:255; B:115). The distribution of coral reefs on Setan Island was mapped using Sentinel-2A satellite images from April 2023, recording data downloaded from the provider's official website.

From the image processing results, the distribution of coral reefs on Setan Island is dominated by fringing reefs and reef flats in shallow waters, especially in the east and south. In addition to fringing reefs in the northern part, many macroalgae and sand substrates dominate the eastern part.

Next, the area of each map classification from the satellite image processing results was calculated using the geometry operation in ArcGis. The coral reef area calculated using calculate geometry is 13.18 ha or 47.55% of the total shallow waters of Setan Island. The area of

macroalgae is 5.06 ha (18%), and sand is 9.48 ha (Table 4). Macroalgae, as producer organisms, play an important role in coastal and small island ecosystems[12] and affect the condition of coral reefs.

Table 4. Results of calculating the area of each classification on the map

No	Class	Broad (ha)	Percentage (%)	Color Description
1	Sand	9,48	34,21	Yellow
2	Macroalgae	5,06	18,25	Brown
3	Coral Reef	13,18	47,55	Purple
Totally		27,72	100	

Table 5. Accuracy test results of data classification and field identification

Field identification / Classification result	Sand	Macroalgae	Coral Reef	Total	User (%)
Sand	8	1	1	10	80
Macroalgae	2	7	1	10	70
Coral Reef	0	1	9	10	90
Total	10	9	11	30	
Producer (%)	80	77,7	81,8		
Total accuracy (%)	80				

Macroalgae are competitors of coral reefs for living space. Coral reef growth is disrupted by algae that can cover and block sunlight penetration, making it difficult for corals to photosynthesize[13]. Macroalgae also play a role in climate change mitigation, as they are predicted to benefit from ocean acidification. As autotrophic organisms, macroalgae increase carbon dioxide and bicarbonate concentrations for photosynthesis and growth[14]. Macroalgae contribute to carbon fixation, accounting for up to 50% of the world's carbon fixation and 71% of the carbon stored in marine sediments[15].

Macroalgae are not a threat to corals but rather primary producers that provide a food source for herbivorous fish and support coral reef ecosystems. In addition, macroalgae can be used as indicators of pollution in estuary and coastal waters because they are sessile, widely distributed, available throughout the year, tolerant of various conditions, and easy to identify and maintain in the laboratory[16].

The faster growth rate of algae compared to coral reefs negatively impacts corals. Sahroni et al.[17] stated that the relationship of macroalgae is inversely proportional to the percent live coral cover, where a decrease in macroalgae cover characterizes an increase in live coral cover.

Data Accuracy Test Results

Accuracy tests were conducted based on ground check results in the field with ten predetermined sample points for each class. Classification accuracy was assessed by producer accuracy, user accuracy, total accuracy, and kappa coefficient. Producer accuracy assesses factual conditions in the field, while user accuracy measures image classification accuracy. Total accuracy shows the overall accuracy of objects on the map that match the field conditions.

The kappa coefficient considers errors in the classification process, so its value is lower than the total accuracy, which only finds the correct data between the classification results and the field conditions. The accuracy test used the confusion matrix table on 30 predetermined validation points (Table 5).

The total accuracy of the coral reef distribution map was 80%. User accuracy for each class, namely sand, macroalgae, and coral reef, was 80%, 70%, and 90%, respectively. The producer accuracy for

these classes was 80%, 77.7%, and 81.8%, respectively. The kappa coefficient of 0.7 indicates a medium confidence level (agreement) (Table 6).

Table 6. Groundchek results (field assessment)

No	Longitude	Latitude	Classification Result	Field State	True/false	Photo Documentation
1	100° 25' 0.942" E	1° 12' 52.823" S	Sand	Sand	Correct	
2	100° 24' 56.851" E	1° 13' 5.455" S	Coral reef	Coral reef	Correct	
3	100° 24' 52.083" E	1° 12' 51.725" S	Sand	Macroalgae	False	

Table 7. Comparison of accuracy of research data

Research	Image used	Location	Number of samples	Data Accuracy
This research (2023)	Sentinel-2a	Setan Island	3 Coral reefs Macroalgae Sand	80%
Littaqwa[18]	Sentinel-2a	Gili Village Gede Indah, NTB	4 Sand Coral reef Seagrass Vegetation	82%
Sari[19]	Google earth engine	Kabung Island	3 Living Coral Dead Coral Sand or Substrate	94,30%
Fuad[20]	Sentinel-2a	White Sand Beach, East Java	3 Living coral Dead Coral Sand	72,20%

An accuracy of 80% is considered good because it exceeds 70%, and according to SNI 7716:2011, it requires a minimum accuracy of 60% for coral reef mapping with medium-resolution imagery. This high accuracy is due to the Sentinel-2a satellite image recording the Setan Island area with less than 30% cloud cover per the data provider's limits. Putro & Tjandrasa[21] stated that cloud cover affects map accuracy. In addition, other factors such as data processing accuracy, number of samples, and number of classes also affect accuracy[22].

Table 6 shows the difference in accuracy results. Satellite images using Google Earth Engine have very high data accuracy, although there is no significant difference from this study. Various factors cause the difference in processing accuracy. Factors affecting accuracy, such as cloud cover, data processing accuracy, and the number of samples and classes, have been explained previously.

Coral Reef Cover Condition

The results of the analysis of the percentage of coral conditions based on live corals per station are presented in Table 8.

Table 8. Percentage of coral condition based on live corals

Station	Percentage of Living Corals (HC)		Category[2]	
	Depth 3	Depth 6	Depth 3	Depth 6
1	31,36	30,50	Fair	Fair
2	26,47	18,36	Fair	Poor
3	23,26	17,34	Poor	Poor
4	3,40	0,33	Poor	Poor

Based on the analysis in Table 8, coral conditions in the waters of Setan Island are classified as fair to poor, with a percentage of 0.33% to 31.36%. The worst condition was at station IV at a depth of 6 meters, while fair conditions were found at station I towards the north at 6 m and 3 m. Anthropogenic activities, tourism, and other factors in the area may influence this.

Table 9. Results of the analysis of the percentage of cover conditions based on the form of growth

Lifeform	Percentage of live corals (HC)							
	ST I		ST II		ST III		ST IV	
	3 m	6 m	3 m	6 m	3 m	6 m	3 m	6 m
Acropora Branching	0,07	0,27	0,47	0,07	1,47	2,07	0,00	0,00
Coral Branching	2,91	13,58	2,33	3,00	0,33	0,00	0,00	0,00
Coral Encrusting	0,20	1,00	0,27	0,27	4,20	2,60	0,27	0,13
Coral Foliose	0,41	1,20	0,20	0,07	0,13	1,27	0,20	0,00
Coral Massive	27,56	13,98	22,67	14,95	17,00	11,40	2,93	0,20
Coral Mushroom	0,07	0,07	0,13	0,00	0,00	0,00	0,00	0,00
Coral Submassive	0,14	0,40	0,40	0,00	0,13	0,00	0,00	0,00
Total Percentage	31,36	30,50	26,47	18,36	23,26	17,34	3,40	0,33
Cover Category	Simply	Simply	Simply	Bad	Bad	Bad	Bad	Bad

At Station I, which has a depth of 3 m, the highest percentage of coral cover was recorded at 31.36%, and it is located in the northern part of Setan Island. With a flat beach contour towards the sea, Station II became the location of tourist activities such as swimming, snorkeling, and diving, which caused more significant pressure on corals. Arisandi et al.[23] stated that coral reefs are more susceptible to disease in tourist areas than in areas without tourism activities. Indrabudi[24] also noted that coral cover decreased in areas with high human activity. Disturbances such as fins friction and coral damage by ship anchors that are not by procedures exacerbate these conditions[25].

The most extensive distribution of life forms was found at Station I at a depth of 3 and 6 m, with seven types of corals: Acropora branching (ACB), Coral branching (CB), Coral encrusting (CE), Coral foliose (CF), Coral massive (CM), Coral mushroom (CMR), and Coral submassive (CS). The lowest distribution is

at Station IV at a depth of 6 m, consisting only of Coral encrusting (CE) and Coral massive (CM). The most significant percentage of cover is dominated by coral massive (CM) at Station I, which has a depth of 3 m, amounting to 27.25%. In contrast, the smallest percentage is dominated by Acropora branching (ACB) and Coral mushroom (CMR) at 0.07%. The high cover of coral massive (CM) is related to high water turbidity, which is in line with the low cover of Acropora branching (ACB), which tends to live in clear waters. This supports Suharsono's[26] statement that Acropora branching grows in clear waters and wave break areas. Barus[27] states that Coral mass dominates in waters with strong currents and high turbidity due to its adaptability to these conditions.

The coral form reflects environmental conditions, with morphologies forming as adaptations to local conditions. Reef-building corals react differently to environmental stresses like temperature, depth, and currents. These factors are thought to influence variation in coral form. Environmental fluctuations will affect coral growth rates, shape, and reproductive capabilities[28].

Relationship between Physical Characteristics of Waters and Coral Reefs

The quality of the water influences the condition of corals on Setan Island. The results of water quality measurements on Setan Island are presented in Table 10.

Table 10. Results of water quality measurements on Setan Island

STATION	Coordinates		Latitude			
	Latitude	Longitude	Temperature (°C)	Current speed (m/det)	Salinity (‰)	Brightness (m)
1	01°12’50.5”	100°25”00.7”	30,9	0,13	30	6
2	01°13’08.5”	100°25”02.1”	27	0,10	33	6
3	01°13’06.2”	100°24”54.8”	30,5	0,16	31	6
4	01°12’49.6”	100°24”50.6”	31,7	0,10	30	6

Based on Table 10, the water temperature ranged from 27°C to 31.7°C, with an average of 30.02°C. The current speed ranged from 0.10 to 0.16 m/s, averaging 0.12 m/s. Salinity ranged from 30 to 33‰, averaging 31‰, and brightness at all stations reached 6 m or 100%.

The results of measuring water parameters show that the temperature on Setan Island is still within the threshold set by PP No. 22 of 2021, which is 28-30 ° C, thus supporting coral growth. Arini[29] stated that the optimal temperature for coral reefs ranges from 23-30°C, with a minimum limit of 18°C, while temperatures below 15°C will inhibit coral metabolism. Hadi et al.[2] added that the ideal temperature is 27-29°C, although corals can tolerate temperatures up to 36-40°C. As Thamrin[30] explained, significant temperature increases can cause coral bleaching and death if it lasts long.

Salinity is the dissolved salt content in seawater. The average measurement results show salinity does not exceed the threshold for coral biota, which is 33-34‰ according to PP No. 22 of 2021. Nybakken[31] states that corals cannot survive in abnormal salinity, with an ideal range of 32-35‰. Salinity supports the life of marine biota, including corals[32]. In Indonesia, salinity generally ranges from 28-33‰. Station II recorded the highest salinity due to the lack of freshwater influence and calm currents. Banjarnahor[33] explained that salinity is influenced by water circulation, evaporation, rainfall, river flow, and water stirring by waves and wind.

Brightness is closely related to light, where the higher the brightness of a body of water, the deeper the light can penetrate. Light is the most crucial factor in coral reef growth[31]. Brightness is considered important as a parameter of coral reef health as it relates to light penetration utilized by

zooxanthella for photosynthesis. The threshold set through PP No. 22 of 2021 is >5 m. The average measurement results show that the incoming light intensity is still in good condition, exceeding the threshold for coral marine life, although not too far from the limit.

The average current speed on Setan Island is in a slow category[34] and plays a role in water circulation, food supply, oxygen, and coral fertilization processes. The fastest current was recorded at Station III at 0.16 m/s, possibly due to currents from the open sea to the southwest of Setan Island. At Station III, the dominant coral form was coral massive (17.00% at 3 m depth and 11.40% at deeper depths), indicating that strong currents and waves tend to support the growth of dense or massive corals.

Corals with branching growth forms are commonly found in calm waters because this adaptation allows them to receive more light. Arisandi[23] stated that waves affect the shape of reef colonies. Corals in sheltered areas (leeward zones) have slender and elongated branching, while in wavy solid areas (windward zones), branching tends to be short, intense, and creeping. The lowest currents were recorded at Stations II and IV due to their geographical location protected by Sumatra Island and Cubadak Island, thus avoiding strong winds and waves.

4. CONCLUSION

The coral distribution map found a coral reef distribution area of 13.18 ha or 47.55% of the total shallow water area in the waters of Setan Island. The shape of the distribution shows the type of fringing reef and reef flat. After the accuracy test, the accuracy value was 80% with a Kappa coefficient of 0.7, which is a suitable category and a moderate level of agreement. The condition of coral reef cover based on live corals in the waters of Setan Island is in the fair and poor categories. Percentages range from 0.33% to 31.36%. The most common types of lifeforms found are coral massive and coral submassive.

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