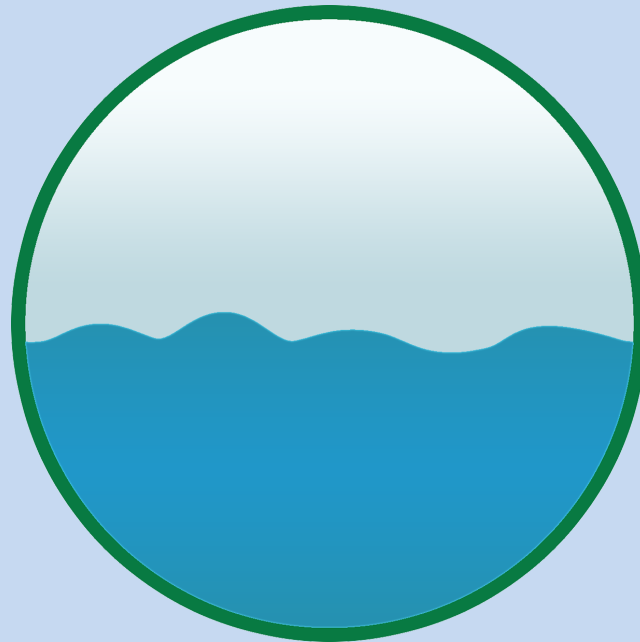


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Distribution analysis of coral reefs for development of marine tourism in Weh Island, Aceh, Indonesia

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ABSTRACT

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Coral reefs are a coastal ecosystem with enormous potential for both marine and human life. The distribution of coral reefs provides the greatest benefits for marine tourism activities. Still, marine tourism has a very large effect on the development of coral reef distribution, while development of marine tourism is an industry that is currently growing very rapidly. This study analyzes the distribution of coral reefs for developing marine tourism in Pulau Weh (Sabang). This study uses Landsat 8 OLI image data and field observations. Image processing methods consist of geometric, radiometric, atmospheric, and water column correction (Lyzena). The technique used in this research is the image data analysis technique using multispectral classification. The results showed that the coral reefs on Weh Island (Sabang) in 2020 amounted to 13,136,000 Ha (63.92%). Coral reef damage on Pulau Weh (Sabang) was caused by two factors, namely artificial factors (human activities) and natural factors. Artificial factors (human activities) include diving, snorkeling, ship waste disposal, café buildings, and fishing. Meanwhile, nature is a high sea surface temperature, which is 29,910C. To overcome the damage to coral reefs caused by human activities in the development of marine tourism, it is necessary to create marine tourism zones to maintain the sustainability of coral reef ecosystems, given the very small growth of coral reefs every year.

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Introduction

One of the ecosystems found in shallow water areas is coral reefs. Coral reefs are abundant ecosystems that live in coastal areas with the greatest productivity and have a very important role in maintaining biodiversity and providing benefits to other species that live in coastal regions (Gapper et al., 2019; Xu & Zhao, 2014). In addition, coral reefs have great social benefits for human life. (Wolff et al., 2015) currently, the social benefits of coral reefs are decreasing, such as the loss of diversity and fish biomass and the loss of other symbiotic organisms on coral reefs caused by overfishing, coastal development that does not pay attention to the environment, excessive use of coastal areas, and marine tourism of coral reefs.

The coastal area has the greatest attraction for tourists to visit (Leposa, 2020). A coastal area is a

place where marine tourism contributes to regional income (Roelfsema et al., 2018). Globally, the tourism sector contributes 1.7 trillion revenue from the export revenue sector from tourists (UNWTO, 2019). The potential of marine tourism is one of the most developed global tourism industries (Dimitrovski et al., 2021; Tegar & Gurning, 2018). The development of marine tourism is one of the problems that is currently getting global attention from government agencies, tourism developers, tourism managers, tourists, and tourism researchers (Cong & Chi, 2020; Duh et al., 2016; Orams & Lück, 2014). Many activities that can be done in marine tourism such as “recreational boating, cruises, swimming, recreational fishing, snorkeling, diving (Miller & Auyong, 1991; Miller, 1993; Hall, 2001). As understood, this marine tourism involves activities in the marine environment and travel activities to

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tourist attractions. The development of marine tourism has an impact on the physical environment and social environment. Therefore, it is necessary to develop sustainable marine tourism (Dimitrovski et al., 2021).

In general, there are three main pillars of sustainable marine tourism development, namely economic sustainability, social sustainability, and environmental sustainability. Sustainability-oriented marine tourism development needs to be focused on correcting past mistakes and preventing future errors; therefore, it is important to evaluate the sustainability level of marine tourism development (Yfantidou & Matarazzo, 2017).

In recent decades coral reef-based marine tourism has developed rapidly in almost all coastal areas. This will directly impact the sustainability of coral reef ecosystems (Spalding et al., 2017; Wong et al., 2019). Sustainability impacts are formed as two positive and negative sides (Kinseng et al., 2018). If viewed from the positive side, if there is a sense of concern for the local community and the government, it will have a positive impact on the existence of a coral reef conservation area (Roberts et al., 2012) which can be used as educational tourism for environmental conservation, especially in marine tourism (Puspitaningrum et al., 2018). However, there are negative impacts if it is not done with a caring attitude. Research from (Pereyra et al., 2021) mentions that maritime tourism activities by doing scuba diving will disrupt the coral reefs. Result from (Kurniawan et al., 2016) mentioned that Gili Matra, Lombok, Indonesia has environmental degradation. Other research also shows that the development of marine tourism, such as creating recreational facilities for snorkeling, reef walking, and diving will disrupt the coral reefs. (Barker & Roberts, 2004), port construction (PIANC, 2010), caching fish and pollution that affects sediment from land (Hannak et al., 2011; Wibawa et al., 2020). One area with the potential for abundant coral reef ecosystems and marine tourism development is Weh Island.

Weh Island is in Sabang City, Aceh Province, Indonesia. Weh Island is a marine conservation area managed by the Laot Adat Institution system through a decree from the Mayor of Sabang in 2010. This is confirmed by the designation of Weh Island as a Marine Conservation Area as a Marine Nature Reserve (Keputusan Menteri Kelautan dan Perikanan Republik Indonesia No. 57/ KEPMEN – KP/ 2013). The decision as a conservation area because of various kinds of marine resources and organisms live in the waters of Weh Island Sabang, such as benthic habitats, seaweed, mangroves, and coral reefs (Najmi

et al., 2020; Rahmadi et al., 2021). Weh Island has the potential for coral reef ecosystems in almost all of its coastal areas and is dominated by fringing coral reefs (Wibawa et al., 2020). Furthermore, Weh Island also has the potential of coral reefs that can be used for marine tourism activities (Kim & Park, 2015)(Chan, 2015). Even so, there are still many places that need to be developed (Chan, 2015). Therefore, the need for development through mapping the distribution of coral reefs (Spalding et al., 2017).

One widely used technique in coral reef distribution in remote sensing and mapping techniques. According to (Goodman et al., 2020). Remote sensing has a very important role in monitoring and managing coastal areas with abundant natural resources, such as the distribution of mangroves and coral reefs. Furthermore, remote sensing of coral reef ecosystems aims to obtain information about coral reef distribution, geomorphology, composition, and coral reef health (Xu & Zhao, 2014). Coral reef distribution data collection needs to be carried out on an ongoing basis to determine the distribution of changes and coral reef health from time to time. The distribution of coral reefs can experience changes (reduction and addition) caused by human activities (coral reef marine tourism).

The story of marine tourism must be carried out professionally and wisely, one of which is mapping the distribution of coral reefs. Mapping of coral reefs attracts the attention of the World's research. Like research from (Paulangan et al., 2019) which maps the distribution and condition of coral reefs in Tanah Merah Bay, Jayapura, Indonesia. Research from (Spalding et al., 2017) also mapped the global value and distribution of coral reef tourism. The results of this study indicate that coral reefs have economic value in the tourism sector and contribute to state income. (Andréfouët & Guzman, 2005) used remote sensing to analyze the geomorphological diversity and status of coral reefs in the Kuna Yala Islands, Caribbean Panama. Based on this research, remote sensing is the right method to map the distribution of coral reefs. However, as an archipelago, the analysis of the distribution and condition of coral reefs in Weh Island has never been studied. This has an impact on the lack of awareness to develop sustainable maritime tourism and care about sustainability.

This study aims to map the distribution of coral reefs on Weh Island in 2020 to develop marine tourism. In addition, this study aims to describe marine tourism activities and environmental conditions that affect the development of coral reefs. Marine tourism activities must be managed wisely to create sustainable and sustainable maritime tourism

so that the preservation of coral reef ecosystems is not damaged due to maritime tourism activities. (Hamyton, 2017) coral reef ecosystem mapping helps understand and manage the coral reef environment.

Materials and Methods

Location and time of research

This research was conducted on Weh Island, Aceh. Weh Island is located at 5°53'50" North Latitude and 95°20'03" East Longitude. The climatic conditions of Weh Island consist of two seasons, namely the west and east seasons and two transitional seasons. Weh Island is directly adjacent to the Indian Ocean in the north and the Malacca Strait in the south. Weh Island is included in the administration of Sabang City, Aceh Province. This research was conducted from July 2020 – December 2021. For more details, the location of this research can be seen in Figure 1.

Based on Figure 1, the potential of coastal ecosystems found on Weh Island can be seen. This study uses primary data (image data) and secondary data (field survey). The research data used in this study can be seen in Table 1 for more details.

Data processing

Landsat 8 OLI image data processing aims to correct sensor errors and record atmospheric conditions and weather disturbances. As a result, the image can be used optimally to map the distribution of coral reefs on Weh Island. Data processing consists of several stages: geometric correction, radiometric correction, image cropping according to the study area, and image classification. For more details, the stages of image processing are described in the following subsections.

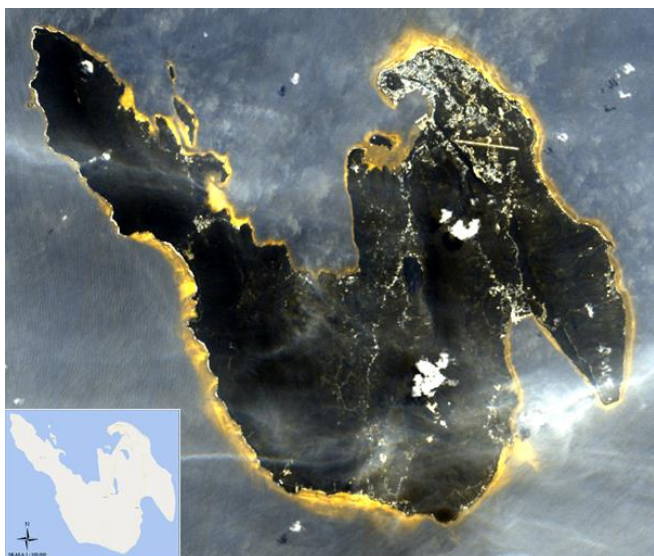


Figure 1. Map of research locations (Source: Landsat 8 OLI Imagery in 2020).

Geometric correction

The geometric correction used in this study is an image to geometric image correction using the Landsat 8 OLI image correction reference in 2019. The Landsat 8 OLI image is an L1-T (level one terrain corrected) image free from sensor errors. For more details, the results of the geometric correction can be seen in Figure 2.

Table 1. Types and sources of research data.

No.	Data	Data source
1.	Landsat 8 OLI Recording Images 2020	United States Geological Survey
2.	Map RBI Number 0421-53 dan 0421-54	Badan Informasi Geospasial
3.	Photo Transect	Field Survey
4.	Interview	Field Survey
5.	Documentation	Field Survey



Figure 2. Image to image geometric correction results (Source: Data Processing, 2020).

Radiometric correction

The radiometric correction in this study consisted of several stages, namely modification of the radian, atmosphere, and water column. Radiometric correction is carried out to obtain good image quality to provide maximum results for the distribution of coral reefs. Radian correction uses the Digital Number equation to convert the spectral radian value on Landsat 8 OLI. The equations used are:

$$L\lambda = ML * Q_{cal} + AL$$

Information:

$L\lambda$: Radiance Value

ML: Radiance multiplicative scaling factor the band

Qca: Digital Number

AL: Radiance additive scaling factor for the band



Figure 3. Radian Correction Results (Source: data processing, 2020).



Figure 4. Results of atmospheric correction (FLAASH) (Source: data processing, 2020).

Atmospheric correction aims to eliminate errors caused by the influence of the atmosphere on the image during the recording process. The atmospheric correction used in this study is the FLAASH correction. Although atmospheric correction (FLAASH) generally does not visually change the image, image data changes occur in the image histogram value. Atmospheric correction (FLAASH) uses a radian corrected data source. For more details, the results of the atmospheric correction (FLAASH) can be seen in [Figures 4](#).

Water column correction aims to minimize the effect of the water column on the image to maximize sampling for image classification. The water column correction uses the equation developed by [Lyzena \(1978\)](#). The Lyzena equation uses the attenuation

coefficient ratio of the water attenuation model of the visible channel pair ([Figure 5](#)).

Image cropping aims to separate objects in the image between the study and non-study areas. In this study, the shot cuts using visual techniques using the administrative map of Weh Island.

Image classification is the final stage of image data processing to produce coral reef distribution maps. The image classification used in this research is multispectral image classification with the Mahalanobis distance algorithm. In addition, image classification uses object sample data (ROI), where the user controls the amount and separability of image data.

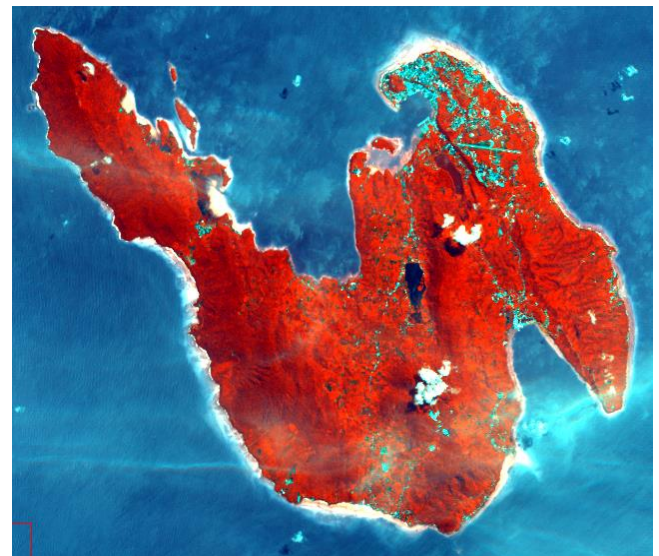


Figure 5. Image of water column histogram correction (Lyzena) (Source: data processing, 2020).

Results

Coral reef distribution

The distribution of coral reefs is the distribution of coral reefs in Weh Island based on image classification results. Multispectral image classification based on Mahalanobis distance using channels 3-4, 2-3, and 1-2 corrected by the water column (lyzena). The use of the multispectral classification of the Mahalanobis distance algorithm gives the best results among other algorithms, and this is due to several things, such as the poor visual quality of the Landsat 8 OLI image of Weh Island and many atmospheric errors. For more details, the input image for classification and image classification results can be seen in [Figure 6](#).

Based on the results of the multispectral classification, the distribution of coral reefs on Weh Island is found in almost all coastal areas.

Multispectral image data gives classification results as many as three classes, namely available substrate, coral reefs, and sand. More details can be seen in Table 2.

Based on Table 2, the distribution of coral reefs is 13,136,000 Ha (63.92%) of the real objects classified. The low number of classes organised is caused by the poor image quality and many atmospheric errors (See Figure 7). The number of atmospheric errors reduces the image quality in the data processing.

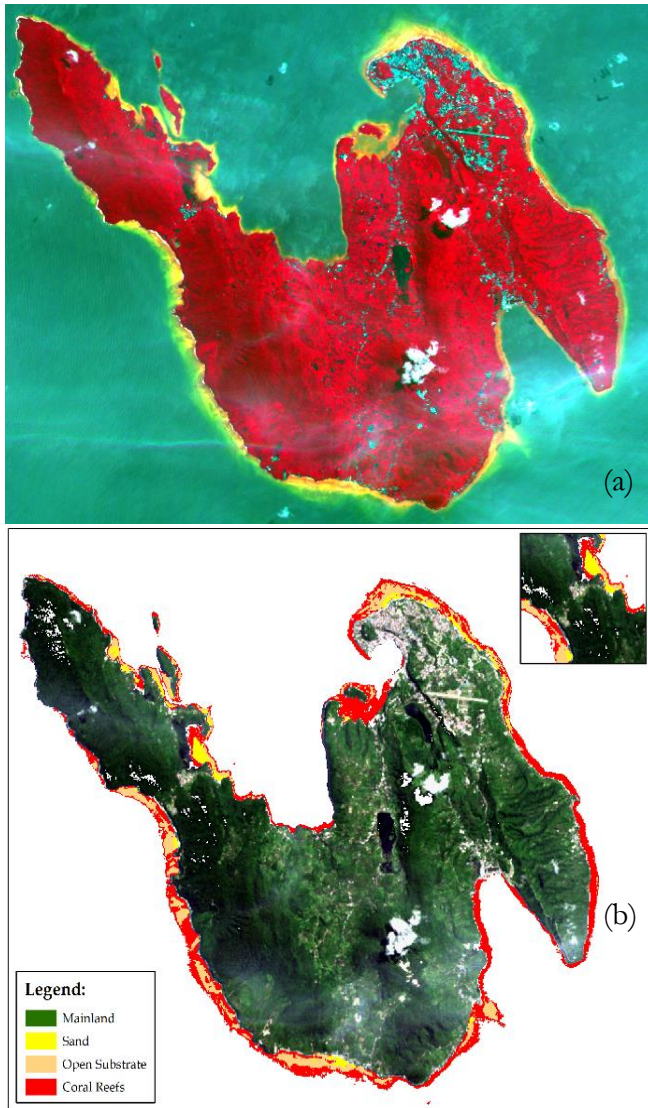


Figure 6. (a) Water column RGB composite image (Lyzenga) and (b) Image classification results (Source: data processing, 2020).

Table 2. Area of multispectral classification result objects in 2020.

No	Object	Large (Ha)	Percentage (%)
1.	Open Substrate	6.120.000	29.79
2.	Sand	1.294.000	6.29
3.	Coral reefs	13.136.000	63.92
	Amount	20.550.000	100

Source: data processing, 2020.

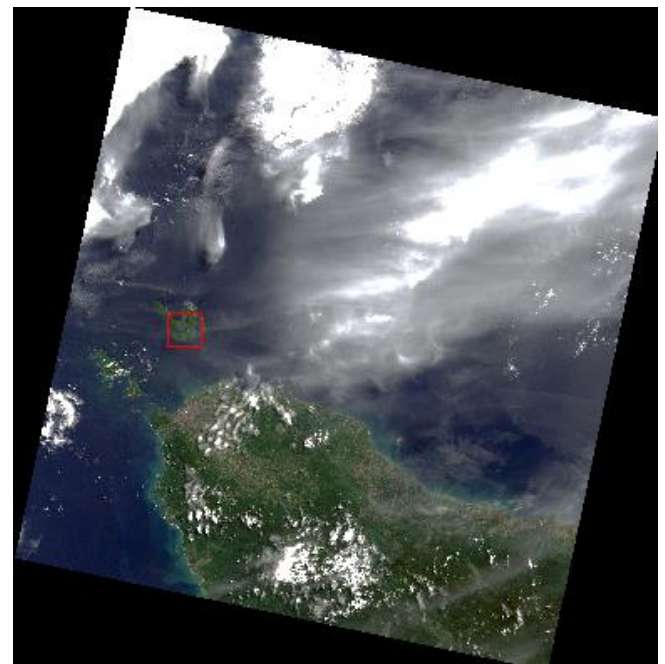


Figure 7. Landsat 8 OLI 2020 imagery (Source: USGS earth explore 2021).

Discussion

Marine tourism activities

Based on the field survey results, marine tourism activities in the waters of Weh Island consist of various activities, including diving, snorkelling, ship waste disposal, building cafes, and fishing (fishing). The most favorite location for diving activities is the Rubiah Marine Park. Based on the results of the documentation conducted, it is stated that diving activities have a very large effect (the movement of divers that change water conditions and changes in water pressure) for coral reefs due to the fragile structure of coral reefs. Another activity in diving that affects coral reefs is the activity of touching coral reefs while diving and is the thing most often done by divers (Barker & Roberts, 2004); Krieger & Chadwick, 2013); (Giglio et al., 2020).

Snorkeling activities are not much different from diving. This activity is the prima donna of attractions offered on Pulau Weh. Excessive tourism activities in snorkeling and not preserving coral reefs such as breaking (for souvenirs), and touching will make coral reefs unable to develop (Worachananant et al., 2008). This is also confirmed by research from (Abidin & Mohamed, 2014) which states that coral reefs are sensitive marine plants. Some unintentional movements such as standing, walking, or dragging diving and snorkeling equipment will destroy coral reefs. Snorkeling can also carry sediment in the form of sand that settles on coral reefs and blocks sunlight for photosynthesis (Lyons et al., 2015).



Figure 8. Marine tourism activities on Weh Island.

In recent years, the interaction of humans and nature has accelerated ecosystem changes. Especially on Pulau Weh. Historically, it has been opened to the general public for the development of an integrated economic center since 1998 through Keppres no. 171 (Mustaqim, 2018). Since then, Sabang's history as a tourism place has begun to open, especially after the conflict. Pulau Weh is a free trade area that is a transit port for international ships and ships exporting shrimp farming business products. According to the results of research in the field, damage to coral reefs was also caused by the release of anchors for cargo ships and cruises which caused damage to the coral base. In addition, the spill of waste oil from fishing boats and commercial vessels along the coast of Pulau Weh exacerbated the damage to coral reefs. The same thing was said (Sarong et al., 2013) which states that the damage occurred due to the contamination of heavy metals in the water.

Community activities on land will directly affect the condition of the waters around Weh Island. Increased tourism activity has led to an increase in infrastructure development, both hotels and cafes in coastal areas. The café development is located around Ujung Sekundo Beach and Pulau Klah Beach which has a beautiful panorama. Research from (Wibawa et al., 2020) mentions that infrastructure development should take into account accessibility and environmental sustainability considerations. (Giglio et al., 2020) mentions that the management of infrastructure development is the main consideration for the realization of sustainable tourism.

Another activity that exists at several places on Pulau Weh is fishing. Pulau Weh is a paradise for anglers because it has a diverse fish population. Most of the domestic tourists do fishing activities by renting a boat. However, fishing activities depend on weather conditions. In addition to fishing activities found, several fishing activities in looking for fish

that affect the decline in the number of coral reefs such as using fish bombs. This result is supported by (Mustaqim, 2018) which stated that the use of fish bombs and poison on Pulau Weh caused the condition of coral reefs to worsen. (Hughes et al., 2007) mentions that good fishing management supports good ecosystem function and coral reef resilience. Based on the research results, activity has an effect that can damage the condition of the coral reef ecosystem in the waters of Weh Island. More details on marine tourism activities can be seen in Figure 8.

Water environment condition

The condition of the aquatic environment is one of the conditions for good living for coral reefs, and this is because coral reefs have a tolerance limit on water conditions. According to (Nyabakken 1998), coral reefs have limitations in accepting water conditions, including temperature conditions ranging from 26-28°C, current movement, light intensity, salinity ranging from 34-35/00 and water pH ranging from 8.2 -8.5.

Based on the field survey results, the average condition of the water quality on Weh Island has conditions beyond the limits of the ability of coral reefs to live, namely 29.91°C. Furthermore, according to (Reid et al. 2012), temperature changes of 1°C - 2°C put great pressure on coral reefs for bleaching. For more details, the temperature and pH conditions of the waters of Weh Island can be seen in Figures 9 & 10.

Marine tourism development

The development of marine tourism is one of the activities that must be carried out to manage sustainable marine tourism and maintain the condition of the natural ecosystem of the waters of Weh Island. According to Alier et al., (2010); Wolff et al., (2015); Abelson et al., (2016); Amoamo et al., (2018), The development of sustainable and sustainable marine tourism is always related to the context of the economy, environmental protection, culture, and social preservation (Ridhwan et al., 2020). However, all global, national, and territorial marine tourism developments do not directly impact society, culture, and the environment if they do not have an interrelated plan between agencies, tourism managers, and the community. Currently, the development of marine tourism, especially coral reef tourism, is faced with several challenges, one of which is unclear coordination between government agencies, vague mandates and functional overlaps, lack of management capacity, and lack of political capacity to implement coral reef marine tourism (Dirhamsyah, 2007) the development of marine tourism on Weh Island must have clear

concepts and frameworks such as zoning marine tourism areas, this aims to maintain coral reef ecosystems and provide benefits for agencies, communities, tourism managers, and tourist. according to (Yulianda, 2007) Marine tourism zoning can be grouped into four zones, namely core zone, special zone, buffer zone, and utilization zone. For more details, the zoning of marine tourism areas can be seen in the following Table 3.

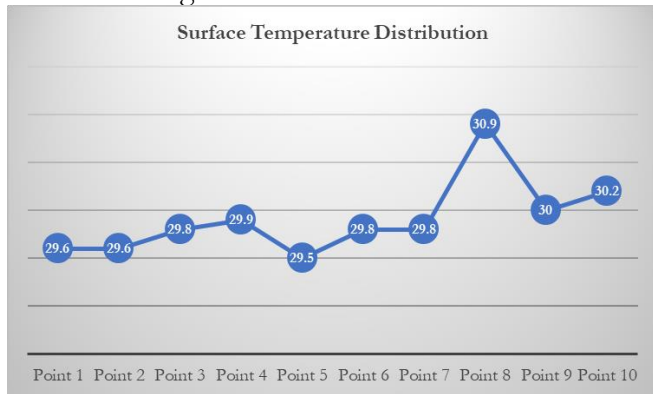


Figure 9. Distribution of surface temperatures on Weh Island (Sabang).

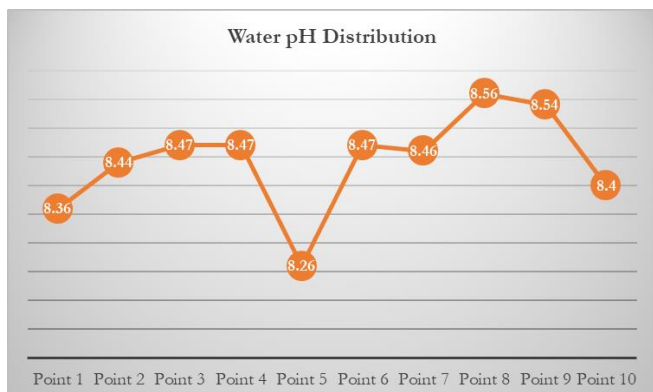


Figure 10. Distribution of pH in the waters of Weh Island.

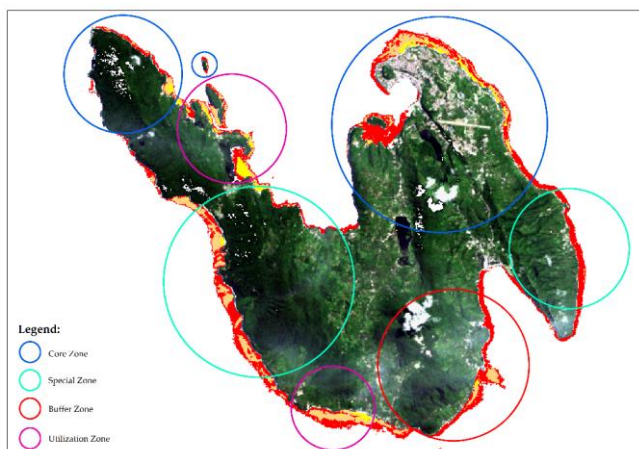


Figure 11. Zoning map of coral reef ecosystem utilization for marine tourism development on Weh Island (Source: data processing, 2021).

Table 3. Zoning of marine tourism areas.

Zone	Objective	Information
Core Zone (I) (10–20%)	Protecting highly vulnerable animals and ecosystems	Forbidden to enter
Special Zone (II) (10–20%)	Limited use for special purposes (research, nature lover, adventurer, diver)	The number of visitors is limited with permits and special rules so as not to cause disturbance to the ecosystem
Buffer Zone (III) (40–60%)	As a buffer zone created for the protection of core and special zones	Can be used limited to ecotourism with minimal disruption to core and special zones
Utilization Zone (IV) (10–20%)	Development of natural tourism, including the development of natural tourism facilities	Requirements: stability of landscapes and ecosystems, resistance to various human activities that take place in them

Source: Yulinda (2007).

Based on the zoning table for marine tourism areas, the development of nautical tourism on Weh Island must implement zones that are accessible to tourists in maritime tourism activities (snorkelling and diving); this is due to the sensitivity of coral reef ecosystems to the influence of human activities. However, based on a field survey, the coral reef ecosystem on Weh Island is in an unhealthy condition. According to (Rahmadi et al., 2021), Coral reef ecosystems with moderate conditions on Weh Island have an area of 710.01 Ha, while healthy coral reefs have a place of 277.38 Ha. For more details, marine tourism zoning on Weh Island can be seen in Figure 11.

Conclusion

The research shows that the coral reefs on Weh Island in 2020 amounted to 13,136,000 Ha. The results of the multispectral classification show 63.92% of the entire coastal area of Pulau Weh. Research findings also show that community activities, both conventional activities, and tourism activities, are abundant along the coast of Pulau Weh. Activities that affect the condition of coral reefs are diving, snorkeling, ship waste disposal, building cafes, and fishing. Based on the results of interviews, the condition of coral reefs is much influenced by the condition of indigenous people who have started to build tourism supporting infrastructure (cafés and resorts) as well as fishing and ponds.

The research findings also show that the average condition of Pulau Weh is not good for coral reef

growth. It is shown that the water temperature condition on Sabang Island is 29.91°C outside the limit of the ideal temperature conditions for coral reefs. However, the pH conditions on Pulau Weh are included in conditions suitable for the growth of coral reefs, namely an average pH of 8.4. For the development of marine tourism, Sabang already has four zones to maintain coral reef ecosystems. Based on the research results, it is hoped that there will be support between local communities, managers, local governments, and tourists to maintain coral reef ecosystems.

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