GeoPlanning
Journal of Geomatics and Planning
Vol. 9, No. 2, 2022

e-ISSN: 2355-6544

Received: 30 October 2022;
Accepted: 15 December 2022;
Published: 15 December 2022.

Keywords:
Coral Reef, Lyzenga, Unsupervised, Human Activities, Rubble

*Corresponding author(s)
email: manessa@ui,ac.id

Original Research Open access

Spatial Distribution of Coral Reef Degradation with Human Activities in the Coastal Waters of Samatellu Lompo Island, South Sulawesi

Muhammad R. A. Pratama[1], Masita D. M. Manessa[1*], Supriatna[1], Farida Ayu[1], Muhammad Haidar [2]

1. *Department Geography, Faculty of Mathematics and Science, Universitas Indonesia, Depok, West Java, Indonesia*
2. *Takeuchi Laboratory, Remote Sensing of Environment and Disaster, Institute of Industrial Science, The University of TokyoUniversity of Tokyo, Tokyo, Japan*

DOI: 10.14710/geoplanning.9.2.121-132

Abstract

A healthy coral reef ecosystem can be beneficial for the survival of fish habitats and aquatic ecosystems. This study aims to analyze the influence of human activities on the spatial distribution of coral reefs in the coastal waters of Samatellu Lompo Island, Pangkajene Islands Regency, South Sulawesi in 2000, 2014, 2018, and 2021. The spatial distribution of coral reefs was obtained through a field survey using the underwater transect photo method. Then, satellite images were processed by using the Lyzenga algorithm for water column correction, and aquatic objects were classified by using k-mean unsupervised classification. Human activities that affect coral reef destruction were obtained through interviews and it was strengthened with related literature studies. The results showed that the coral reefs in the coastal waters of Samatellu Lompo decreased from 2000-2021. In 2000, the live coral area was 13.53 ha, whereas in 2021 it was 8,031 ha. Destructive fishing activities such as using bombs and poison in catching fish are the main factors of coral reef destruction. In addition, destructive fishing activities commonly occur in the western and northern waters of Samatellu Lompo that causing the live coral into dead coral or rubble.

1. Introduction

Indonesia is one of the six countries in the Coral Triangle that is building a marine protected area (MPA) system at the national and local levels (White et al., 2021). Therefore, there is a lot of potential for marine resources both fishery resources and coral reefs diversity (Syarif, 2009). Indonesia is one of the areas rich in the diversity of coral reefs, this matter because Indonesia is located in the coral triangle (Quevedo et al., 2021). Based on Bellwod's research, it can be seen that Indonesia is a region with the highest diversity of fish and coral species in the Indo-Pacific (Bellwood et al., 2005). This is indicated by the existence of several types of coral reefs, namely approximately 480 species of coral, with ecosystem processes that affect the life of more than 700 species ornamental fish (Fadli, 2009; Sinansari & Priono, 2019). However, the existence of living coral reef areas in Indonesia continues to experience degradation `which results in a decrease in coral diversity (Salinas-de-León et al., 2013). The condition of damaged coral reefs is quite large (i.e., 30.4%), while the living coral reef is lower (i.e., 27%) (LIPI, 2014).

Increasingly damaging coral reefs can be caused by several things, mostly by many human activities such as shipping activities, illegal fishing, the presence of active tourism, and urbanization activities (El-Naggar, 2021). While on natural factors, physical environmental factors have an influence significant factor that play a role in the existence of good coral reefs are in the form of factors, salinity, depth, temperature, and from the presence of turbidity in the waters (Shah, 2021). Besides that, salinity, currents, waves, and tides also affect development coral reefs (Haris et al., 2021). The cause of physical damage can be seen in damage or erosion carbonate skeleton of a colony and raised from the substrate on the reefs (Chabanet et al., 2005). The Spermonde Archipelago, South Sulawesi Indonesia has the highest amount of destructive fishing in Indonesia (Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 114/KEPMEN-KP/SJ/2019, 2019). According to Haya & Fujii (2017), the condition of coral reefs in the Spermonde Islands, South Sulawesi Province, there has been high coral degradation. One of island in Spermonde Islands namely Samatellu Lompo Island has bad coral reef status with a 10% decrease in live coral area (Haya & Fujii, 2017; Nurdin et al., 2019). The decrease in the live coral area were replaced with an increase in dead coral and seagrass (Nurdin et al., 2019).

Remote-sensing technology has an important means of monitoring and surveying areas of coral reefs distributed in a cost- and time-effective manner (Kutser et al., 2003). Based on these problems, it is needed to monitor damage to coral reefs by utilizing remote sensing technology with multispectral image processing (Hedley et al., 2016). Multispectral data can be applied in the use of mapping bathymetry, namely mapping the seabed which has estimated waters shallow (Jaelani et al., 2019). In the process, it is necessary to develop techniques combining information and multispectral bands to produce a depth-invariant index of the bottom cover material (Lyzenga, 1978 in Manessa et al. (2016). Reflectance of reef communities (algae, coral, and sand) shows an increase in the visible range from 400 to 700 nm with a degree of local minimum near 675 nm due to chlorophyll absorption (Hochberg & Atkinson, 2003).

Based on several previous studies, Landsat Imagery is one of the multispectral images that can be used for coral reef mapping i.e., El-Askary et al. (2014); Iqbal et al. (2018); Nurdin et al. (2015). Time-series optical multi-band with Landsat imagery with the improving geolocation accuracy provide detailed information over time (Wang et al., 2019). From the problems above, this study is intended to carry out an influence analysis of human activities on the distribution of coral reefs in the Island Waters Area Samatellu Lompo, Pangkajene Islands Regency, South Sulawesi. Expected within this research, the people there can pay attention to the condition of the marine ecosystem on the island Samatellu Lompo so the degradation of coral reefs can be suppressed and their condition improved.

2. Data and Methods

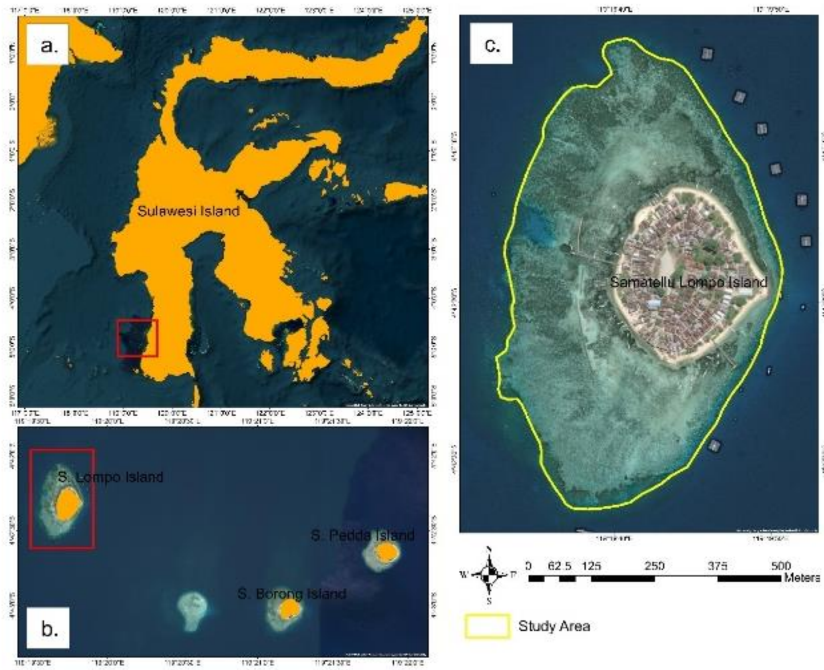
2.1. Study Areas

This research was conducted in the shallow sea waters of Samatellu Lompo Island. The research area is located at coordinates 119⁰ 16' 60.2" E and 40⁰ 42' 42.96" S. Samatellu Lompo Island located at the administrative area of Mattiro Walie Village, Liukang Tupabbiring Utara District, Pangkajene and Islands Regency, South Sulawesi Province. Samatellu Lompo Island is bordered by others small islands, such as Samatellu Pedda Island and Samatellu Borong Island to the southeast (Figure 1).

2.2. Environmental Data

The variables used in this study are the distribution of coral reefs, NDBI, and human activities (Figure 2). Coral reefs distribution data was obtained from benthic habitat mapping using Landsat 7 ETM+ imagery for 2000 and Landsat 8 TIRS imagery for 2014, 2018 and 2021. The result will be validated using benthic habitat in situ data. Benthic habitat in situ data was obtained by direct measurement using the Underwater Photo Transect method. Benthic habitat data will be classified into live coral, dead coral/rubble, seagrass, and sand. Whereas, the NDBI function is to see population growth from the density of buildings to obtain from Landsat 7 ETM+ imagery for 2000 and Landsat 8 TIRS imagery for 2014, 2018 and 2021. In addition, information on human activities that damage to coral reef ecosystems was obtained through a literature study and conducting interviews with informants consisting of local residents, local fishermen, and researchers who have visited and observe the Samatellu Lompo shallow water area.

DOI: 10.14710/geoplanning.9.2.121-132



Source: Data Analysis Result, 2022

Figure 1. Study area: a.) Map of Sulawesi Island; b.) Samatellu Lompo Island and Neighboring Islands; c.) Shallow Sea Waters of Samatellu Lompo Island

2.3. Processing Data Methods

In indicating the condition of coral reef distribution in 2000, 2014, 2018 and 2021, the Lyzenga algorithm was used for water column correction and proceed with classify water objects with unsupervised classification. The data processing was done using Google Earth Engine and ArcGIS pro software (Figure 2). The following are the steps in the processing of satellite imagery:

1. **Downloading Landsat Surface Reflectance Satellite Image data for the Year 2000, 2014, 2018 and 2021.** Landsat and Sentinel satellite imagery that be used are surface reflectance images, so atmospheric correction is not needed.

2. **Displays images in Red Green Blue (RGB) format.** Landsat 7 bands the bands used are 3,2,1. While on Landsat 8 bands are used Bands 4,3,2.

3. **Water Roughness Correction.** Calculating the average wavelength in the deep sea with the formula (Lyzenga 1978 from Manessa et al. (2016)):

$$Xi = \log(\rho i - \rho\infty i)$$

   As ρi is Reflectance Value, and $\rho\infty i$ = Average deep-sea value.

4. **Water Column Correction.** Find the slope to compare the blue and green bands, or blue bands with red sure between Band 1 and Band 2, Band 2 and Band 3, and Band 1 with Band 3 on Landsat 7. Whereas on Landsat 8, namely Band 2 with Band 3, Band 3 with Band 4, and Band 2 with Band 4, written as follows (Lyzenga 1978 from Manessa et al. (2016)):

$$Yij = Xi - ki\,kj \cdot X\mathrm{j}$$

DOI: 10.14710/geoplanning.9.2.121-132

As Xi and Xj : Band i and j which have been transformed, ki/kj : Water irradiance attenuation coefficient in band i and j.

5. **Masking.** Masking process aims to separate between the waters and land areas. The masking process is accomplished by digitizing manually.

6. **Unsupervised classification.** The process of unsupervised Classification of the k-mean algorithm produces groups of benthic habitat objects. Then, the results will be validated with in-situ benthic habitat data generated from Underwater Photo Transect (UPT). The validation process is carried out by matching the secondary data that has been generated.

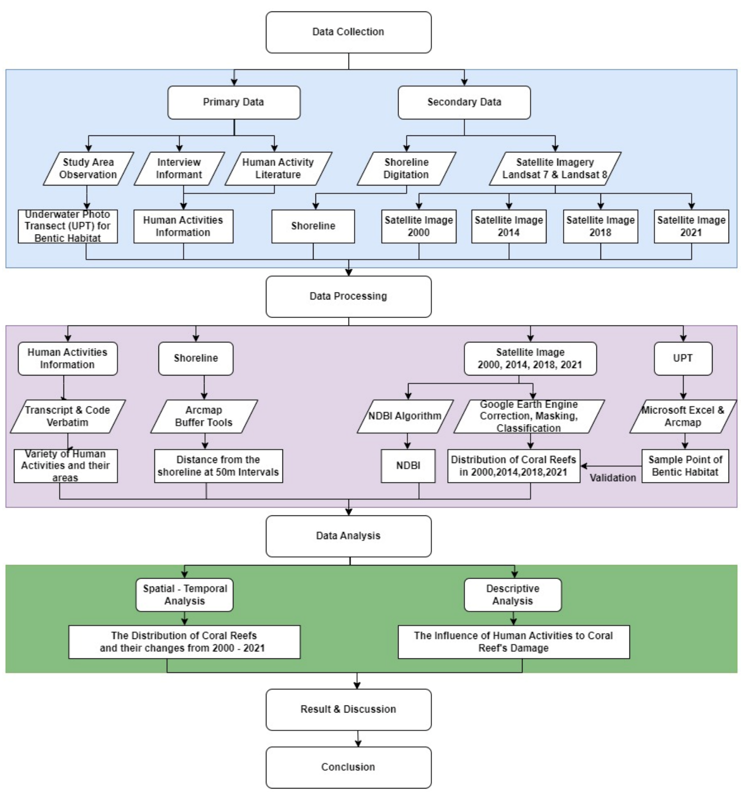
7. **Normalize Different Build-up Index**. NDBI data processing in mapping building density uses the following formulation (Zha et al., 2003):

$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

As SWIR and NIR is Shortwave infrared and Near Infrared band of Landsat-7 and 8 image.

2.4. *Data Analysis*

Spatial analysis in this study describes the distribution and damage of coral reefs in the Samatellu Lompo waters area. Furthermore, the temporal analysis explains changes in coral reefs in 2000, 2014, 2018, and 2021. Through these changes can be obtained the damage to coral reefs in the waters area. On the other hand, descriptive analysis in this study was conducted by interpreting the data result. In addition, a descriptive analysis was also carried out to explain human activities that occur in water areas and their impact on damage to the coral reef ecosystem in the Samatellu Lompo Island waters area (Figure 2).



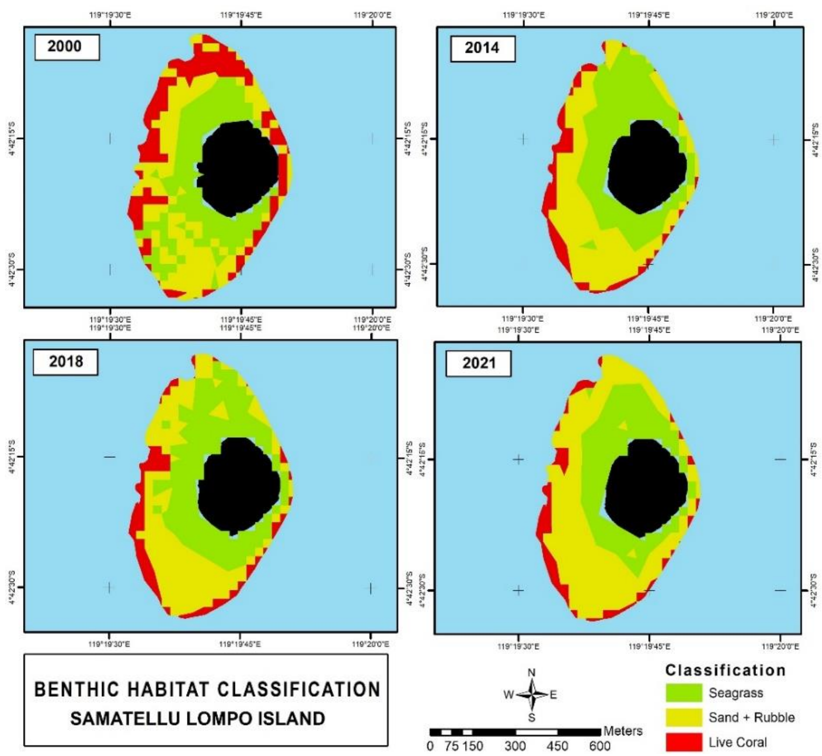
Source: Identification, 2022

Figure 2. Research Methodology Workflow

3. Result and Discussion

3.1. *Coral Reefs Distribution*

The distribution of coral reef can be seen from the results of processing satellite images Landsat 7 ETM+ and Landsat 8 TIRS after implementing the Lyzenga water column correction algorithm along with k-mean algorithm classification. Reef distribution coral observed with Landsat imagery namely in 2000 with Landsat 7 ETM + and, 2014, 2018, and 2021 using Landsat 8 TIRS. The data processing consists of 4 benthic habitat classes, namely live coral, rubble, sand, and seagrass. In general, from year to year the area of live coral reduces. In 2000 the area of live coral reached 13.53 ha in percentage 37.35%. However, in 2014 and 2018 the area of live coral has decreased of 8.84 ha and 8.448 ha. Then in 2021, live coral will decline return even though not significantly, namely up to 8,031 ha or with percentage 22.14% (Figure 3).



Source: Data Analysis Result, 2022

Figure 3. Benthic Habitat Classification

3.2. *Data Validation*

The accuracy test carried out by using a confusion matrix. The accuracy test aims to compare the results of images that have been classified with the actual object from observation data in the field (Wahidin et al., 2015). The distribution of sample point data generated from the Underwater Photo Transect can be seen in Figure 4. This accuracy test is carried out on the results of image processing in 2021, the year in which it was carried out field survey for validation. The results of the distribution of field samples produce living coral objects a total of 45 samples. While the seagrass object is equal to 63 samples. On the sand object having a total of 15 samples, as well as dead coral fragments or also called rubble namely has 32 samples. So, the total benthic habitat samples taken were 155 samples (Figure 4). The value shown through the confusion matrix with Landsat satellite imagery is equal to 77.5% with detailed calculations as follows.

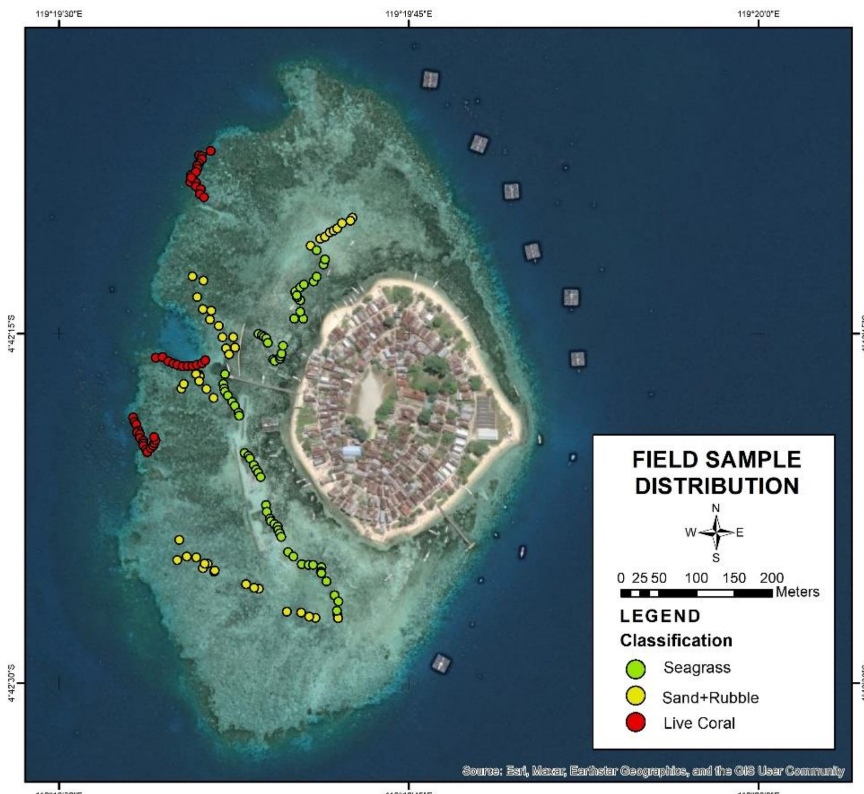
$$\text{Overall Accuracy} = (39+28+55)/155 * 100\% = 77.5\%$$

The results of the confusion matrix accuracy test between field survey validation and satellite imagery Landsat 8 with a spatial resolution of 30 m has a pretty good result of 77.5%. Accuracy test for benthic habitat refers to Geospatial Information Agency i.e., level value minimum accuracy of 60% (Table 1).

Table 1. Accuracy Test Confusion Matrix

No	Object	Sand + Rubble	Live Coral	Seagrass	Total	*User's Accuracy*
1	Sand + Rubble	39	0	8	47	82.97%
2	Live Coral	17	28	0	45	62.2%
3	Seagrass	8	0	55	63	87.3%
	Total	64	28	63	155	
	Producer's Accuracy	60.937%	100%	87.30%		Overall Accuracy: 77.5%

Source: BIG, 2014

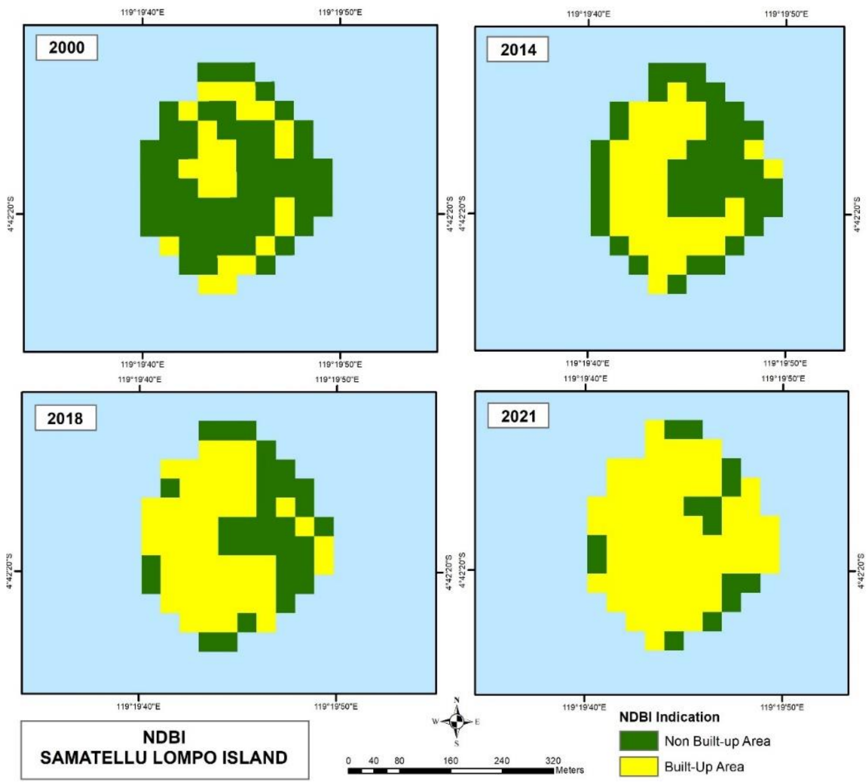


Source: Data Analysis Result, 2022

Figure 4. Field Sample Distribution

3.3. Normalized Difference Built-Up Index (NDBI)

Based on the results of processing and interpretation of NDBI data, this study produces an indication of the class of non-built-up areas and built-up areas. In 2000, the non-built-up area class dominated the island with an area of 5.4 Ha. However, in the northern part, it is indicated there is already a built-up area which indicates there is already a population inhabiting this island. Then, in 2014 there was an increase in the class built-up area of 1.44 Ha from the north to southeast. Despite that condition, the area of the non-built-up area still dominates the island. An increase in the built-up area class also occurred in 2018 with an increase of 1.08 Ha in the west and east. In contrast to previous years, in 2018 the area of the built-up area dominated the island area with a total area of 4.68 Ha. Then, in 2021 the built-up area class almost dominate all areas of the island with a total area of 6.3 Ha. Based on this description, it can be seen that from 2000 – 2021 there has been an increase in the built-up areas in the Samatellu Lompo Island. This is in line with the total population, where an increasing built-up area is followed by a population increase. Accordingly, it can be seen that Samatellu Lompo Island has experienced an increase in population (Figure 5 and Table 2). As indicated in Table 2, the increase in buildup area is connected with the decline in live coral area and increase in sand-rubble area.



Source: Data Analysis Result, 2022

Figure 5. NDBI in Samatellu Lompo Island

Table 2. Changes in Coral reef and NDBI Class from 2000, 2014, 2018, and 2021

No	Class	2000		2014		2018		2021	
		Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
1	Live Coral	13.53	37.35	8.84	24.38	8.45	23.29	8.03	22.14
2	Sand+*Rubble*	9.81	27.06	13.92	38.40	14.17	39.07	15.56	42.91
3	Seagrass	12.90	35.59	13.49	37.20	13.64	37.62	12.67	34.94
Total		36.24	100.00	36.25	100.00	36.27	100.00	36.27	100.00
4	Non-Built-up Area	60.00	5.40	44.00	3.96	32.00	2.88	14.00	1.26
5	Built-up Area	24.00	2.16	40.00	3.60	52.00	4.68	70.00	6.30
Total		84.00	7.56	84.00	7.56	84.00	7.56	84.00	7.56

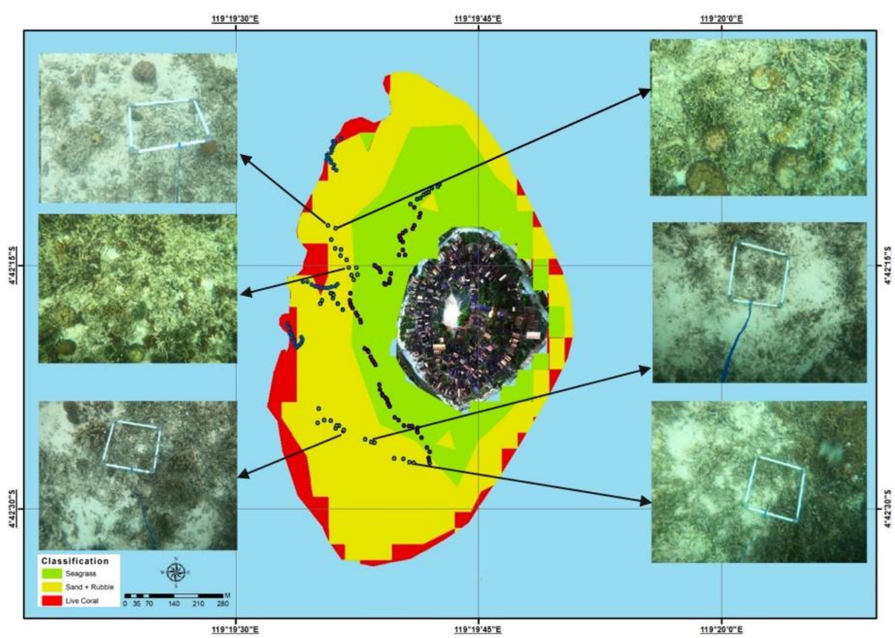
Source: Data Analysis Result, 2022

3.4. Human Activities on the Coral Reefs Ecosystem

Damage to coral reefs in Indonesia is generally caused by several human activities such as fishing activities that are not environmentally friendly (DFW, 2003). The Spermonde people themselves have for a long time using several fishing methods that are not environmentally friendly, such as explosives, toxic materials cyanide, trawl, and others (DFW, 2003). But that is considered the most influential is the use of explosives as well as blasting fish and potassium cyanide (anesthetizing fish). Based on research in 2000, around 214 ships operating in Spermonde using illegal fishing gear and of that amount around 86.5% use materials explosives (Pet-Soede & Erdmann, 1998). Furthermore, based on the Report Coral Reef Rehabilitation and Management Program II - Center & Research (2006), in 2000 the start of large-scale fishing using trawl equipment which is increasingly widespread in Samatellu Lompo waters and other nearby waters.

Based on research by Ahdiat (2014), as many as 8.6% of fishermen in Samatellu Lompo Island saw coral reef destruction activity, namely 20% of the fisherman stated that the activity was carried out more than 3 times a year lastly, but no definite location in the waters of Samatellu Lompo was damaged by members of the public. This is reinforced by the Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 114/KEPMEN-KP/SJ/2019 (2019) which obtained data namely the highest cases of destructive fishing were in the territorial waters of the province of South Sulawesi, and it happened in 2014.

Based on Yusuf et al. (2016), there were no conditions coral reefs that are still good or very good around the waters of the Makassar City and the Spermonde Islands, due to pressure anthropogenic or human impact on these ecosystems and quite a lot of activity catching fish and other coral reef biota in an environmentally unfriendly manner (Figure 6). Amount fishing catches decreased significantly throughout the Spermonde Archipelago after there was activity destroying coral reefs with explosives that caused cover live coral a was only 23.60% or included in the category of severely damaged or badly damaged (Yusuf et al., 2016). Whereas in 2021 we conducted research there to see first-hand the coral reef ecosystem there and conducted interviews with informants about things that are done by the community that can cause damage to coral reefs. The cause of physical damage can be seen in damage or erosion carbonate skeleton of a colony and raised from the substrate on the reef (Fox et al., 2003).



Source: Data Analysis Result, 2022

Figure 6. Rubble Distribution in Samatellu Lompo Waters Area

3.5. Relationship Distribution and Damage of Coral Reefs with Human Activities

From the results of data processing, it is known that the area of coral reefs has decreased from 2000, 2014, 2018 and 2021 (Table 1). The reduced area of coral reef that occurred in the shallow waters of Samatellu Lompo Island shows that coral damage has occurred. The occurrence of fishing by bombing with various chemicals dangerous that has been happening for decades. Based on the experience and knowledge of the informants, that destructive fishing activities at Samatellu Lompo in the early 2000s it was dominated by the use of bombs, with the chemical ammonium nitrate. According to informants, the perpetrators of destructive fishing activities in 2000 generally came from various regions, not just the people of Samatellu Lompo Island. Although unknown it is certain where the perpetrators come from, but it is believed that the perpetrators usually come from far away from Samatellu Lompo Island. Based on the area designated as a destructive fishing zone for fishermen, according to informants in 2000, When the growth of coral reefs in the waters Samatellu Lompo as a whole is very good, so there is no specific zone for the participants unscrupulous perpetrators of destructive fishing in carrying out their activities, which means the whole the territorial waters of Samatellu Lompo has the potential to be damaged by unscrupulous persons engage in destructive fishing activities.

Whereas in 2014, informants said that destructive fishing activities on Samatellu Lompo Island it is widely practiced, the biggest type of destructive fishing is such as using a bomb. Apart from carrying out bombing activities, in 2014, destructive fishing done by poison. Catching fish using materials toxic which is dominated by the use of potassium cyanide (KKP, 2019). This led to a reduction in the area of live coral to 8.84 ha, a decrease of around 4.66% from 2000. Based on data processing of coral reef distribution in 2014, the reduction in coral area most of the lives are in areas that are quite far from Samatellu Lompo Island as well there is still plenty of live coral, but it is still in shallow seas.

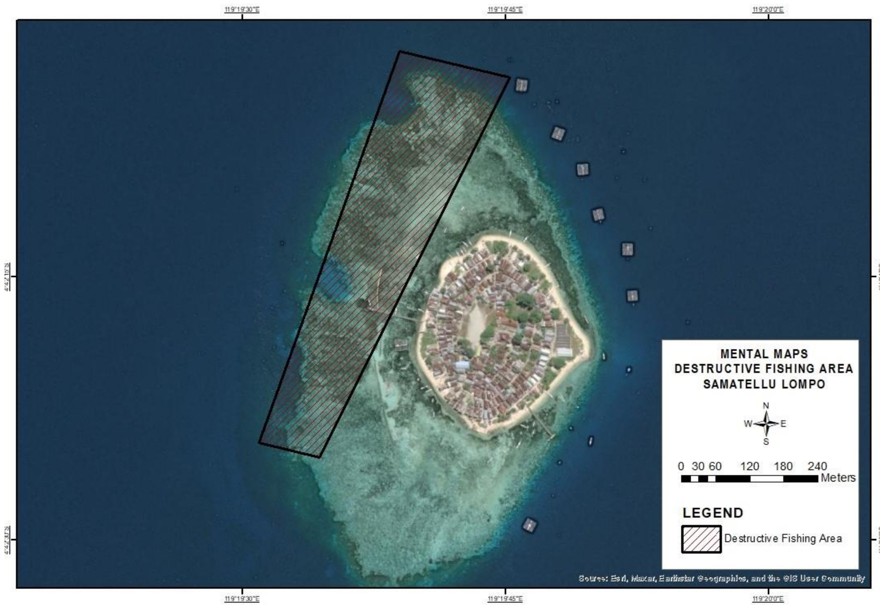
In 2018, the area of live coral was 8.45 ha in proportion 23.29%. This experienced a decrease in 2014 which covered an area of 8.84 ha. Meanwhile, the area of coral fragments combined with sand increased by 0.67% from 2014 or 14.17 ha. In 2018, destructive fishing activities still being carried out by several unscrupulous fishermen. But indeed, fishermen who do this are not from the island Samatellu Lompo and other Samatellu Islands, but in a quite remote area. Based on observations while in the field, many fragments were found coral (rubble) which belongs to the dead coral which is then mixed with sand substrate. Human activities that are detrimental to the sustainability of reef ecosystems coral reefs are allegedly still rife. Destructive fishing activities, namely by carrying out bombings in 2021 are still happening. Additionally in 2021, do poison of coral reefs was also carried out. In fact, according to informants, at this time the fishermen prefer to catch fish by using poison with potassium cyanide as raw material, due to poisoned fish then passed out for some time, so that's when the fishermen catch fish as much as possible.

According to the informants in general, the destructive fishing activities were carried out by unscrupulous fishermen who are outside the area of Samatellu Lompo Island, in fact is outside the village of Mattiro Walie. The fishermen will not deign to destroy their territory themselves, therefore they choose to carry out destructive fishing activities away from them live. When they carry out activities in other water areas, then they will look for areas of coral reefs that are still very good, as well as those that are a bit far from Island of those waters. This is because when engaging in acts like bombing and poisoning, no one is aware of it.

Based on information obtained by informants, mental maps are made, namely as an illustration of something territory and environment, which are developed by individuals on the basis of daily experiences from various sources (Handawati, 2018). From the mental maps obtained based on the experience and knowledge of the informants, destructive fishing activities are based on the existence of a fishing area, according to informant fishing area is in an area that has a coral reef area large, and not close to Samatellu Lompo Island. The informant said that in the west of the territorial waters of Samatellu Lompo Island which is used as territory fishing which is indicated as an area of destructive fishing activities. Apart from that, there were other informants who said that they saw destructive activities fishing in the north of Samatellu Lompo Island. Therefore, the results of the

DOI: 10.14710/geoplanning.9.2.121-132

informant's narrative, areas that are used as destructive fishing which damages coral reefs is in the western and northern regions of the shallow waters area of Samatellu Lompo Island (Figure 7).



Source: Informant's Narrative Data, Data Processing, 2021

Figure 7. Destructive fishing area in Samatellu Lompo shallow water

Research on coral reef mapping on Samatellu Lompo Island has been carried out previously (i.e., Nurdin et al. (2019)). Based on research Nurdin et al. (2019), it is known that an increase in population in an area has an effect on reducing the live coral area. In addition, the reduction of live coral area changes to other habitats. This is in accordance with this research, from 2000, 2014, 2018, and 2021 the population on Samatellu Lompo Island has been increasing. The increase in population is in line with the various human activities it does. Based on informants' data, the most influential human activity is destructive fishing, especially using bombing and toxins. In this study, human activities had an effect on changing living coral areas into other habitats such as rubble and seagrass. Compared to previous research, this study enhances more specific information regarding the extraction of information on NDBI and the changes in other benthic habitats (i.e., rubble and seagrass). In addition, this research also obtained information on the location of destructive fishing activities on Samatellu Lompo Island.

4. Conclusion

The coral reefs in the Samatellu Island Waters Area were extensive in 2000 live coral which is 13.53 ha, while in 2021 live coral will decrease to 8,031 ha. In the last 21 years there has been a reduction in the distribution of coral reefs in the waters area of Samatellu Lompo Island. Human activities are a major factor in the destruction of coral reefs engage in destructive fishing activities, namely fishing activities in a manner that damage such as the ultimate by using explosives or bombing. The areas that are used as destructive fishing activities are in the western and northern regions of Samatellu Lompo waters. Using bombardment can result coral becomes dead and destroyed directly and will become coral fragments/rubble. This area has been designated as a conservation area, but it is not considered optimal because there are still people who carry out these activities who come from outside the island Samatellu Lompo.

5. Acknowledgments

This study was supported by RISPRO LPDP grant number PRJ-41/LPDP/2020.

6. References

Ahdiat. (2014). *Dinamika Pengelolaan Kawasan Konservasi Di Wilayah Perairan Kabupaten Pangkep.*

Bellwood, D. R., Hughes, T. P., Connolly, S. R., & Tanner, J. (2005). Environmental and geometric constraints on Indo-Pacific coral reef biodiversity. *Ecology Letters, 8*(6), 643–651. [Crossref]

Chabanet, P., Adjeroud, M., Andréfouët, S., Bozec, Y.-M., Ferraris, J., Garcia-Charton, J.-A., & Schrimm, M. (2005). Human-induced physical disturbances and their indicators on coral reef habitats: A multi-scale approach. *Aquatic Living Resources, 18*(3), 215–230. [Crossref]

Coral Reef Rehabilitation and Management Program II - Center, & Research, H. U. C. R. (2006). *Rencana Pengelolaan Terumbu Karang (RPTK) Kecamatan Liukang Tupabbiring. Kabupaten Pangkep.*

Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 114/KEPMEN-KP/SJ/2019, (2019).

DFW. (2003). Profile of Destructive Fishing in Spermonde Islands. In *Destructive Fishing Watch Indonesia.*

El-Askary, H., Abd El-Mawla, S. H., Li, J., El-Hattab, M. M., & El-Raey, M. (2014). Change detection of coral reef habitat using Landsat-5 TM, Landsat 7 ETM+ and Landsat 8 OLI data in the Red Sea (Hurghada, Egypt). *International Journal of Remote Sensing, 35*(6), 2327–2346. [Crossref]

El-Naggar, H. A. (2021). Human Impacts on Coral Reef Ecosystem. In *Natural Resources Management and Biological Sciences.* IntechOpen. [Crossref]

Fadli, N. (2009). Growth Rate of Acropora formosa Fragments that Transplanted on Artificial Substrate Made from Coral Rubble. *Biodiversitas Journal of Biological Diversity, 10*(4). [Crossref]

Fox, H. E., Pet, J. S., Dahuri, R., & Caldwell, R. L. (2003). Recovery in rubble fields: long-term impacts of blast fishing. *Marine Pollution Bulletin, 46*(8), 1024–1031. [Crossref]

Handawati, R. (2018). Pengembangan Mental MAP dalam Pembelajaran Geografi di Sekolah. *Spatial: Wahana Komunikasi Dan Informasi Geografi, 18*(2), 84–94. [Crossref]

Haris, A., Dwiantara, I., & others. (2021). Acceleration of Coral Reef Recovery from Bleaching Phenomenon with Transplantation Method in Liukangloe Island in 2019. *Jurnal Ilmu Kelautan Spermonde, 7*(1), 7–15.

Haya, L. O. M. Y., & Fujii, M. (2017). Mapping the change of coral reefs using remote sensing and in situ measurements: a case study in Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia. *Journal of Oceanography, 73*(5), 623–645. [Crossref]

Hedley, J., Roelfsema, C., Chollett, I., Harborne, A., Heron, S., Weeks, S., Skirving, W., Strong, A., Eakin, C., Christensen, T., Ticzon, V., Bejarano, S., & Mumby, P. (2016). Remote Sensing of Coral Reefs for Monitoring and Management: A Review. *Remote Sensing, 8*(2), 118. [Crossref]

Hochberg, E. J., & Atkinson, M. J. (2003). Capabilities of remote sensors to classify coral, algae, and sand as pure and mixed spectra. *Remote Sensing of Environment, 85*(2), 174–189. [Crossref]

Iqbal, A., Qazi, W. A., Shahzad, N., & Nazeer, M. (2018). Identification and mapping of coral reefs using Landsat 8 OLI in Astola Island, Pakistan coastal ocean. *14th International Conference on Emerging Technologies (ICET).* [Crossref]

Jaelani, L. M., Bobsaid, M. W., & Khomsin. (2019). Bathymetric Mapping of Shallow Water using Landsat 8 and Sentinel 2A Satellite Data. Case Study: East Madura's Waters. *IOP Conference Series: Earth and Environmental Science, 389*(1), 12007. [Crossref]

Kutser, T., Dekker, A. G., & Skirving, W. (2003). Modeling Spectral Discrimination of Great Barrier Reef Benthic Communities by Remote Sensing Instruments. *Limnology and Oceanography, 48*(1part2), 497–510. [Crossref]

KKP. (2019). *Rencana Aksi Nasional Pengawasan Dan Penanggulangan Kegiatan Penangkapan Ikan Yang Merusak Tahun 2019-2023.* Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia.

LIPI. (2014). *LIPI: 30,4 Persen Terumbu Karang Rusak.* LIPI. http://lipi.go.id/lipimedia/lipi:-304-persen-terumbu-karang-rusak/9643

Manessa, M. D. M., Haidar, M., Budhiman, S., Winarso, G., Kanno, A., Sagawa, T., & Sekine, M. (2016). Evaluating the performance of Lyzenga's water column correction in case-1 coral reef water using a simulated Wolrdview-2 imagery. *IOP Conference Series: Earth and Environmental Science, 47*(1), 12018.

Nurdin, N., Hatta, M., Mashoreng, S., Amri, K., Pulubuhu, D. A. T., Aris, A., AS, M. A., & Komatsu, T. (2019). *Remote Sensing of Population and Coral Destruction for Long Term on Small Islands.* [Crossref]

Nurdin, N., Komatsu, T., Agus, Akbar AS, M., Djalil, A. R., & Amri, K. (2015). Multisensor and multitemporal data from Landsat images to detect damage to coral reefs, small islands in the Spermonde archipelago, Indonesia. *Ocean Science Journal*, *50*(2), 317–325. [Crossref]

Pet-Soede, L., & Erdmann, M. V. (1998). *Blast fishing in southwest Sulawesi, Indonesia.*

Quevedo, J. M. D., Uchiyama, Y., Lukman, K. M., & Kohsaka, R. (2021). How blue carbon ecosystems are perceived by local communities in the coral triangle: Comparative and empirical examinations in the Philippines and Indonesia. *Sustainability (Switzerland)*, *13*(1), 1–21. [Crossref]

Salinas-de-León, P., Dryden, C., Smith, D. J., & Bell, J. J. (2013). Temporal and spatial variability in coral recruitment on two Indonesian coral reefs: consistently lower recruitment to a degraded reef. *Marine Biology*, *160*(1), 97–105.

Shah, S. B. (2021). Coral reef ecosystem. In *Heavy Metals in Scleractinian Corals* (pp. 27–53). Springer.

Sinansari, S., & Priono, B. (2019). Opportunity and business challenge of marine ornamental fishes in Indonesia as a potential commodity of fisheries. *IOP Conference Series: Earth and Environmental Science*, *230*, 12067. [Crossref]

Syarif, L. M. (2009). Promotion and management of marine fisheries in Indonesia. *Towards Sustainable Fisheries Law*, 31.

Wahidin, N., Siregar, V. P., Nababan, B., Jaya, I., & Wouthuyzen, S. (2015). Object-based Image Analysis for Coral Reef Benthic Habitat Mapping with Several Classification Algorithms. *Procedia Environmental Sciences*, *24*, 222–227. [Crossref]

Wang, R., Cai, M., Ren, C., Bechtel, B., Xu, Y., & Ng, E. (2019). Detecting multi-temporal land cover change and land surface temperature in Pearl River Delta by adopting local climate zone. *Urban Climate*, *28*, 100455. [Crossref]

White, A., Rudyanto, Agung, M. F., Minarputri, N., Lestari, A. P., Wen, W., Fajariyanto, Y., Green, A., & Tighe, S. (2021). Marine Protected Area Networks in Indonesia: Progress, Lessons and a Network Design Case Study Covering Six Eastern Provinces. *Coastal Management*, *49*(6), 575–597. [Crossref]

Yusuf, S., Amri, K., Husain, A. A. ., Rape, R. A., & Supriadi. (2016). *Monitoring Kondisi Terumbu Karang dan Ekosistem Terkait di Kota Makassar.*

Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from {TM} imagery. *International Journal of Remote Sensing*, *24*(3), 583–594. [Crossref]