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Shoreline Dynamics in the Very Small Islands of Karimunjawa – Indonesia: a Preliminary Study

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Abstract

Indonesia is considered one of the biggest archipelagic countries in the world. According to some literature, Indonesia has more than 17,000 islands, most of which are classified as small islands. Some of these islands have become important areas for tourism, for instance, small islands in Karimunjawa. However, some of these islands experienced shoreline changes caused by erosion and accretion. Hence, this research aims to map the spatial distribution of shoreline change using the Digital Shoreline Analysis System (DSAS) add-in on ArcGIS. The primary dataset utilized as input consists of Sentinel 2A imagery captured over 2017 and 2022. The results showed that around 89 segments, or 51.47% of the total shoreline segments, tend to experience accretion, while the remaining 79 segments, or 45.93%, experience erosion. This finding suggests that most shoreline segments tend to accrete or seaward movement in the research area. The results of this study exhibit notable disparities when compared to the occurrences observed in Pandeglang (Banten), Kuwaru (Yogyakarta), Buleleng (Bali), and East Java Province, where coastal erosion prevails over accretion. The managers of the islands try to reduce the threat of erosion by constructing dykes and breakwaters. However, these buildings are ineffective due to the relatively simple structures and building materials. Therefore, further studies are needed to determine the type and specification of mitigation buildings that are suitable for implementation in that location.

1. Introduction

Indonesia is one of the largest archipelagic countries in the world, with a total of 17,000 islands. Most of the islands in Indonesia have an area of less than 2,000 km^2 or can be classified as small islands and less than 100 km^2, which are called very small islands (BIG, 2022; Mutaqin et al., 2022). Furthermore, very small islands are more vulnerable to disasters due to climate change (Koroy et al., 2017; Miller et al., 2020; Mutaqin et al., 2022; Mutaqin, Handayani, et al., 2021). This is due to the condition of very small islands, which tend to have narrow, isolated landmasses and relatively limited resources (Hidayat et al., 2023; Wilkinson et al., 2016). In addition, the relatively flat topography of the very small islands also makes this area somewhat prone to disasters (Handayani et al., 2022; Hidayat et al., 2023; Mutaqin et al., 2022; Mutaqin, Handayani, et al., 2021).

Small and very small islands have great potential to be utilized for various purposes such as tourism, economic zone, and conservation (Miller et al., 2020; Mutaqin et al., 2022; Wisha et al., 2022; Yulianda et al., 2010). For example, the very small islands in the Karimunjawa Islands are essential tourist destinations in Jepara Regency (Fafurida et al., 2020; Pribadi et al., 2020). Tourism in the Karimunjawa Islands has at least been visited by around 30,000 tourists between 2016 and 2020 (Balai Taman Nasional Karimunjawa, 2020). This is inseparable from the natural beauty and facilities offered by Karimunjawa (Figure 1). Besides offering beautiful scenery, tourism activities in Karimunjawa are supported by facilities such as hotels, inns, and food stalls totaling

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115 units by 2021. This shows that Karimunjawa has promising tourism potential (Lukman et al., 2022; Pribadi et al., 2020; Setiawan, 2022).

(a) (b)

Courtesy: Mulyadi Alwi, 2023

Figure 1. a) View from Cemara Besar island and b) hostelries in Menjangan Kecil island

The existence of tourism potential in the Karimunjawa islands requires more attention, not only for its development but also for managing the threat of possible disasters. This is necessary because the area consists of small and very small islands which are relatively vulnerable to climate change hazards such as seawater intrusion, erosion, and flooding (Appelquist et al., 2016; Handayani et al., 2022; Koroy et al., 2017; Micallef et al., 2018). In addition, the Karimunjawa Islands area has also been designated as a National Park through the Decree of the Minister of Forestry No. 78/Kpts-II/1999 issued on February 22, 1999 (Balai Taman Nasional Karimunjawa, 2020), so that protection activities are needed for the ecosystems in those areas.

Karimunjawa is growing because of the Dewadaru Airport, Karimunjawa Harbor, and the development of marine tourism, which has further increased the value and attractiveness of land in the region. As a result, land conversion into built-up land cannot be avoided (Amalia et al., 2018; Anugrah et al., 2017). Currently, apart from tourism, Karimunjawa is also used for productive aquaculture (Yusuf, 2014). On the other hand, Karimunjawa National Park has coastal hazards, including environmental damage, beach erosion, and seawater intrusion (Muhammad & Mardiatno, 2022; Purbani et al., 2019).

One of the dangerous threats found on the coasts of small islands in Karimunjawa is erosion. In some parts of the island, erosion is the main factor causing shoreline changes (Figure 2). This can cause losses when dealing directly with vulnerable components such as tourism support facilities. However, previous research only focused on the main islands, e.g., Karimunjawa and Kemujan, without considering other small islands, which also face severe problems related to coastal erosion (Muhammad & Mardiatno, 2022; Purbani et al., 2019). Therefore, this paper aims to identify shoreline changes associated with the distribution of erosion hazard levels in the Karimunjawa islands using DSAS add-in (Marfai et al., 2022; Mutaqin, Kurniawan, et al., 2021). The results obtained can be used as input for stakeholders in determining the appropriate type of management related to reducing the impact of erosion hazards in the future.

2. Data and Methods

This research focused on the coastal areas of Cemara Besar, Cemara Kecil, Menjangan Kecil, and Menjangan Besar islands, which are essential islands in tourism activities in Karimunjawa (Figure 3). Quantitative methods utilizing remote sensing and geographic information systems are used to conduct research. The primary data used as input is Sentinel 2A imagery with the recording years 2017 and 2022, which can be downloaded at https://apps.sentinel-hub.com/eo-browser/. The image with the year 2017 was chosen because, according to the information collected from the informants, the increase in the number of tourists in Karimunjawa began in 2017. The image with the year 2022 was chosen to obtain the latest data sources, which can be accessed free of charge and has a little cloud cover (Pribadi et al., 2020).

Courtesy: Mulyadi Alwi, 2023

Figure 2. Examples of coastal erosion in a) Cemara Besar, b) Cemara Kecil, and c) Menjangan Kecil islands

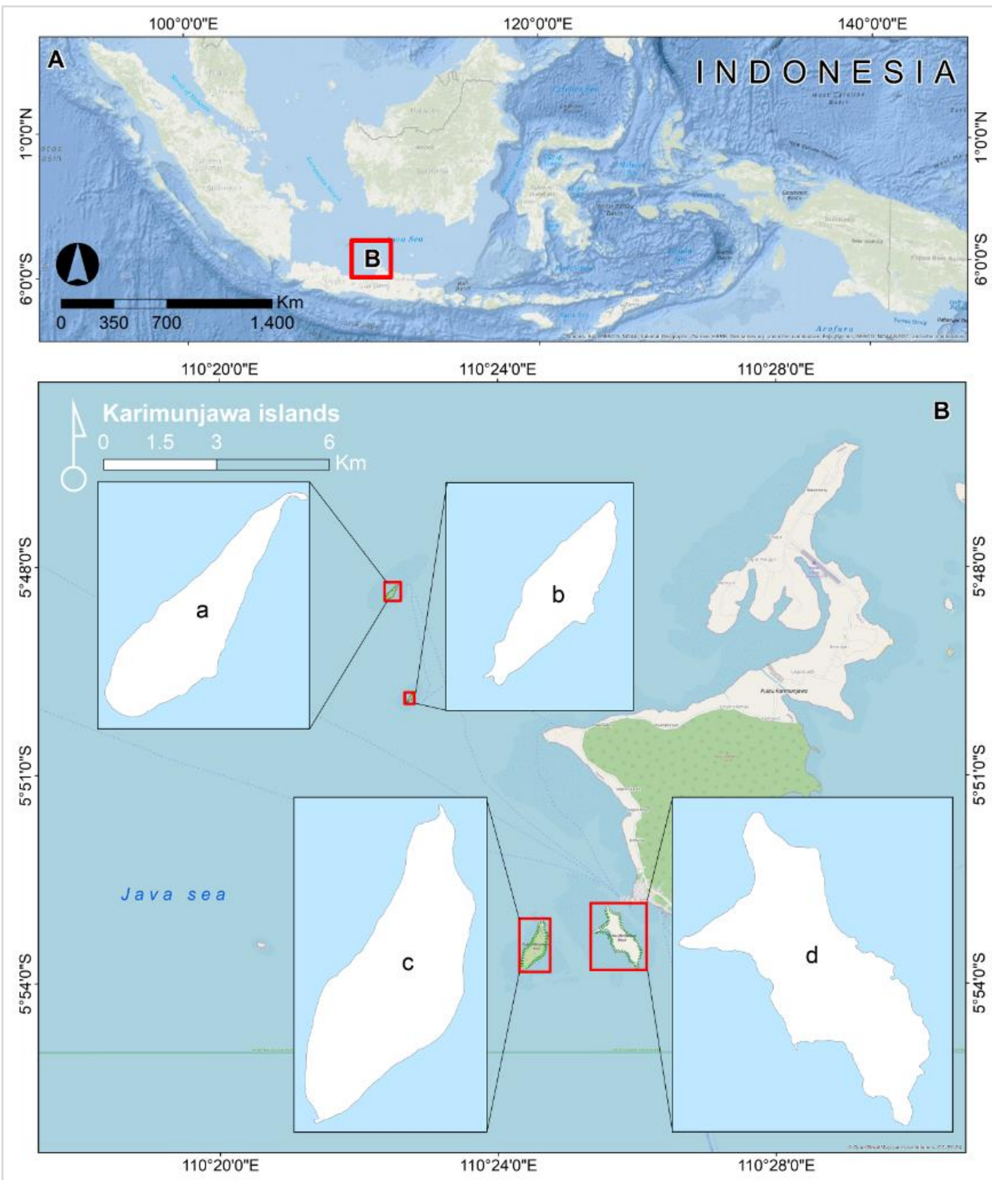


Figure 3. Study area in the very small island of a) Cemara Besar, b) Cemara Kecil, c) Menjangan Kecil, and d) Menjangan Besar

The two images were then interpreted visually to determine the existence of the shoreline. Furthermore, manual digitization was performed using the editing function in ArcGIS software version 10.4 to obtain shoreline data for 2017 and 2022. Because not all parts of the study location could be identified on Sentinel 2A imagery, interpretation was also carried out on Maxar Technologies' imagery accessible on Google Earth Pro software.

The shoreline data obtained were then analyzed using the Digital Shoreline Analysis System (DSAS) add-in version 5 in ArcGIS software version 10.4. Before further analysis, the two shoreline data must be stored in a private database in a single feature class file. Further, a new information column was added to the feature class using the attribute Automator function. This new column adds data source acquisition time information and uncertainty values. The uncertainty value indicates the distance around the shoreline to help determine the location of the intersection point between the shoreline and the transect (Arjasakusuma et al., 2021; Himmelstoss et al., 2021).

In addition, a feature class baseline is also needed, which will be used as a starting point in drawing the transect line. Making the baseline line can be assisted by processing the 2017 shoreline data using the buffer function as the oldest shoreline (Marfai et al., 2022; Mutaqin, 2017). Adding a new column in the feature class baseline containing ID, group, and search information is also necessary. ID and group information are used for grouping on the baseline, while search information is used as a reference value to determine the length of the transect line (Himmelstoss et al., 2021).

Hereafter, it was necessary to fill in several options in the default parameter function according to the information stored in shoreline and baseline attributes and then operate the cast transects function with the maximum search distance, transect spacing, and smoothing distance values of 20,000, 500, and 500 m, respectively. There is no specific interval that should be used related to those parameters. Users can enter the desired spacing distance in meters between transects along the baseline, depending on their needs in their study area (Himmelstoss et al., 2021). The processing results of the cast transects function were used as input to calculate the distance of shoreline changes using the calculate rates function (Arjasakusuma et al., 2021; Handayani et al., 2022; Himmelstoss et al., 2021; Marfai et al., 2022; Mutaqin, Kurniawan, et al., 2021).

Several types of statistics can be used, such as shoreline change envelope (SCE), net shoreline movement (NSM), end point rate (EPR), linear regression rate (LRR), and weighted linear regression rate (WLR) (Himmelstoss et al., 2021). However, in this case, EPR was chosen as a statistic to help identify shoreline changes because it can calculate the value of changes in each shoreline segment (Lazuardi et al., 2022; Marfai et al., 2022; Mutaqin, 2017; Mutaqin, Kurniawan, et al., 2021). The results were then interpreted visually, where a shoreline with a negative EPR indicates erosion, while a positive value suggests accretion (Table 1). The research method diagram/workflow related to this research is shown in Figure 4.

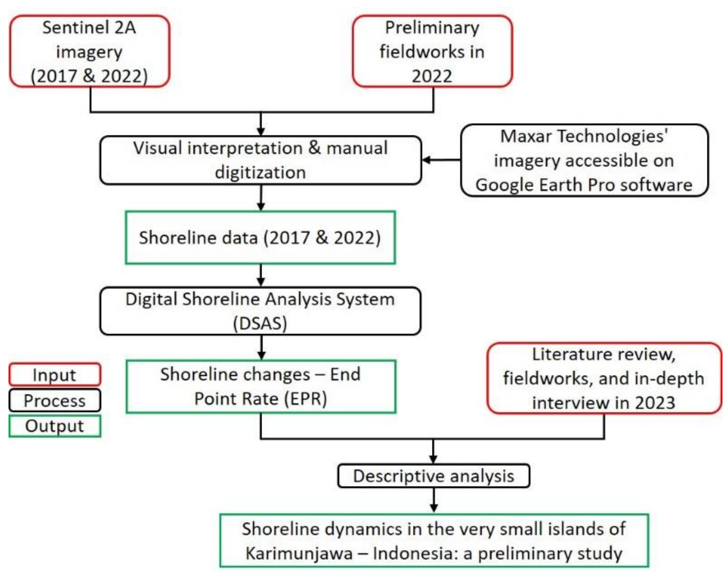


Figure 4. The research Method Diagram/Workflow

Table 1. Category of shoreline changes based on EPR value

No	Category of shoreline changes	EPR value (m/year)
1	Very high erosion	< -2
2	High erosion	-1 to -2
3	Moderate erosion	0 to -1
4	Stable	0
5	Moderate accretion	0 to +1
6	High accretion	+1 to +2
7	Very high accretion	> +2

Source: Nassar et al. (2018)

3. Results and Discussion

Based on the formation process, the Karimunjawa Islands have several geological formations, namely the Karimunjawa Formation (pTk), Parang (Tmpv), alluvium; coastal deposits (Qa), and marl, clay, and limestone deposits (Tmpg) (Mutaqin et al., 2022). The research location, i.e., Cemara Kecil, Cemara Besar, Menjangan Kecil, and Menjangan Besar, comprises the Parang Formation with material in the form of tuffs, volcanic breccias, and lava deposits, as well as formations of a younger age composed of alluvium material and coastal deposits (Mutaqin et al., 2022). The dominant very small islands material consists of alluvium material and coastal deposits may increase the possibility of coastal erosion (Förster et al., 2019; Giardino et al., 2018; Muhammad & Mardiatno, 2022; Mutaqin, 2017).

The results of shoreline data processing using the DSAS add-in, which has been categorized based on Nassar et al. (2018), are then visualized in Figure 5. Our results indicate that approximately 89 segments, or 51.47% of the total shoreline segments, are included in the accretion category, while the other 79 segments, or 45.93%, are included in the erosion category (Table 2). This indicates that most of the 2022 shoreline in the study area tends to experience accretion or shifting toward the sea. This result is quite different from what happened in Pandeglang (Banten), Kuwaru (Yogyakarta), Buleleng (Bali), and East Java Province, which is dominated by coastal erosion than accretion (Arjasakusuma et al., 2021; Marfai et al., 2022; Mutaqin, 2017; Mutaqin, Kurniawan, et al., 2021). This can be caused by many factors, either natural or human-induced. Various natural variables, such as tides, waves, coastal currents, water level, changes in wind direction, storms, and hurricanes-cyclones events, can impact coastal dynamics in the form of erosion and sedimentation (Clifton, 2003; Marfai et al., 2022; Morner, 2017; Mutaqin, 2017; Mutaqin & Ningsih, 2023). The presence of sea walls and other buildings can also affect it (Bird, 2019; Marfai et al., 2022).

Related to the phenomenon of climate change, developing countries such as Indonesia will be significantly affected and not ready to deal with shocks to social, economic, and environmental systems (Koroy et al., 2017; Miller et al., 2020; Mutaqin et al., 2022). In Karimunjawa, climate change will not create new hazards that have never existed but will exacerbate existing hazards, in this case - coastal erosion, and create potential hazards in previously unexposed areas (Bell et al., 2017; Gill & Malamud, 2016; Muhammad & Mardiatno, 2022). In Karimunjawa, coastal erosion co-occurs with other hazards (e.g., ecosystem disruption, gradual inundation, seawater intrusion, and tidal floods) may have a multiplier effect than the coastal erosion that occurs individually (Appelquist et al., 2016; Gill & Malamud, 2016; Micallef et al., 2018).

Table 2. Distribution of shoreline changes in Karimunjawa

No	Category of shoreline changes	Sums of segment	Percentages (%)
1	Very high erosion	52	30.23
2	High erosion	18	10.47
3	Moderate erosion	9	5.23
4	Stable	4	2.33
5	Moderate accretion	10	5.81
6	High accretion	5	2.91
7	Very high accretion	74	43.02

Source: Data analysis, 2023

Coastal ecosystems have an important role in the dynamics and development of the region in Karimunjawa (Pribadi et al., 2020). Climate change can increase the threat of erosion in Karimunjawa, which has a broad impact on coastal areas in the region (Appelquist et al., 2016). Coastal erosion is closely related to extreme weather due to climate change and emerges as a secondary hazard from extreme weather, especially on exposed shorelines. Increased coastal erosion results from stronger storms and higher seas, producing more winds, waves, and floods (Wisha et al., 2022). Therefore, the survival of coastal communities and the sustainability of coastal systems in Karimunjawa are in danger (Muhammad & Mardiatno, 2022; Purbani et al., 2019).

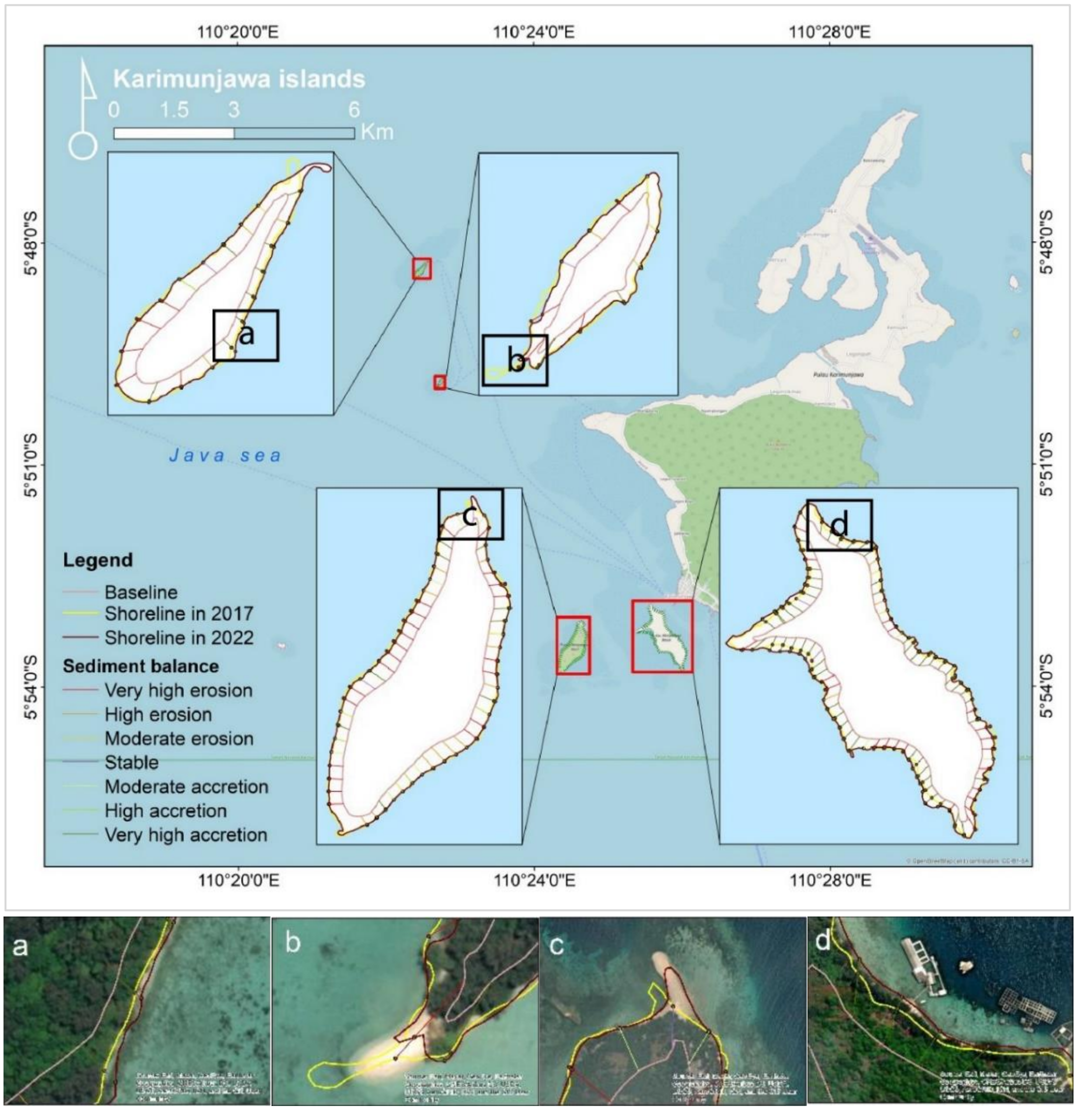
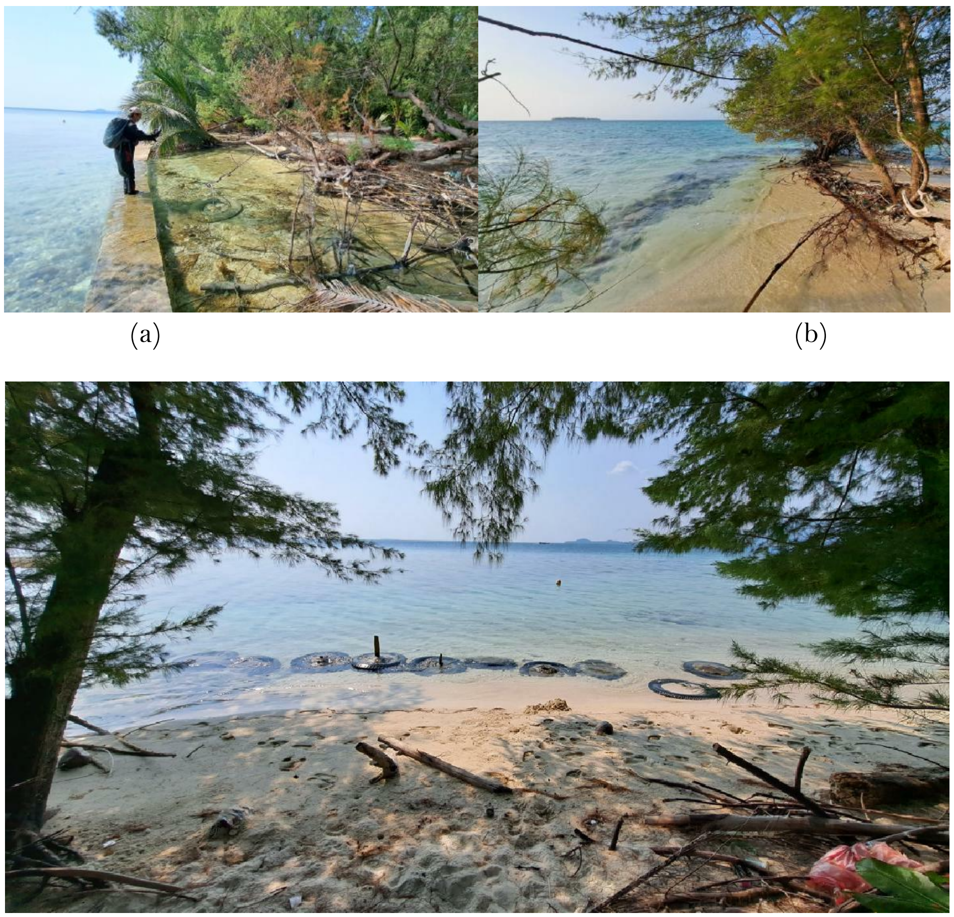


Figure 5. Spatial distribution of shoreline changes in the study area and examples of comparison between 2017 and 2022 shorelines in a) Cemara Besar (accretion), b) Cemara Kecil (erosion), c) Menjangan Kecil (accretion), and d) Menjangan Besar (accretion)

According to information collected from informants, shoreline change in the study area is considered a normal phenomenon that occurs all the time. The informant added that if some shorelines experience landward changes or erosion, other shoreline segments will experience accretion as a form of seeking sediment balance. However, if erosion occurs around a vulnerable component, it can cause a disaster, which can cause property loss (Appelquist et al., 2016; Marfai et al., 2022; Mutaqin, 2017). This condition occurs in some coastal areas in Cemara Besar and Menjangan Kecil islands, where buildings are in the form of stalls and hostelries threatened by erosion. Therefore, island managers try to minimize this hazard by constructing dykes and breakwaters (Figure 6).

However, several structural mitigation buildings are no longer able to function as they should due to changes in the characteristics of hydro-oceanographic variables such as the direction and speed of ocean waves and sediment balance (Appelquist et al., 2016; Kaharuddin & Busthan, 2018; Wisha et al., 2022). The observations in the field indicate that the decrease in the effectiveness of the coastal protection structures is also due to the inadequacy of the building structures or the use of relatively simple materials. Therefore, further studies are needed to determine the type of mitigation that is somewhat suitable to be applied and with the better materials to be considered (Appelquist et al., 2016; Marfai et al., 2022; Micallef et al., 2018).



(a) (b) (c)

Courtesy: Mulyadi Alwi, 2023

Figure 6. Example of structural mitigation from the island managers following the coastal erosion by constructing dykes (a) and traditional breakwaters (b and c)

4. Conclusions

This research aims to map the spatial distribution of shoreline change using the Digital Shoreline Analysis System (DSAS) add-in on ArcGIS. The results showed that around 89 segments, or 51.47% of the total shoreline segments, tend to experience accretion, while the remaining 79 segments, or 45.93%, experience erosion. Some of the erosion that occurs can potentially cause losses because it occurs around vulnerable components in the form of tourist infrastructure such as stalls and hostelries. The managers of the islands try to reduce the threat of danger by constructing dykes and breakwaters. However, some of the buildings that have been built have low effectiveness due to the relatively simple structures and building materials. Therefore, further studies are needed to determine the type and specification of mitigation buildings that are suitable for implementation in that location. Results from this preliminary research will be useful as a baseline for further research related to coastal hazards in very small islands of Karimunjawa. Very high-resolution imagery from Unmanned Aerial Vehicles (UAV) or Remotely Piloted Aircraft Systems Services (RPAS) may be used to obtain more detailed shoreline data in other very small islands. In addition, further thorough research on the characteristics of hydro-oceanographic parameters and their relation to coastal dynamics, especially shoreline changes in very small islands, will be necessary.

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