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Research Article

Study of coastal land change in sand mining activities in Bandar Batauga Village, South Buton Regency, Indonesia

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Abstract

This research focused on land changes in Bandar Batauga Village, South Buton Regency, Indonesia, related to environmentally damaging sand mining activities. The primary objective of this research was to analyze land evolution in coastal settlement areas vulnerable to disasters, with an emphasis on the impact of sand mining until the year 2050. The research methods encompassed quantitative and qualitative approaches, including coastal change analysis using ArcGIS, in-depth interviews, and statistical methods. The research findings highlighted a significant increase in coastline changes, reaching an erosion area of 511.3 m² in 2022. Projections until 2050 indicate a potential maximum erosion of 1,157.22 m². This research employed the analytic hierarchy process, focusing on social, economic, physical, and biotic environmental aspects to formulate disaster mitigation strategies. However, implementing environmental management policies faces challenges, such as a lack of competence in relevant departments and low awareness among mining permit owners. Therefore, strategic recommendations involve enhancing human resource capacity, strengthening oversight, and providing economic support as critical steps to reduce mining activities.

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Introduction

Coastal settlements, especially those in areas prone to land change, are often prime targets of natural disasters (Mentaschi et al., 2018), so it is crucial to analyze land change in disaster-prone coastal residential areas to understand their vulnerability and evaluate their impending environmental impacts (Wright, 2019). A comprehensive understanding of land change is necessary for settlement sustainability and a proactive step in addressing potential disaster threats (Verburg et al., 2015; Turner et al., 2020). Using a land change analysis approach, we can investigate the dynamics and trends of change that occur in coastal settlements (Wang et al., 2021), accompanied by a deeper understanding of the characteristics of land change to find appropriate solutions and management strategies to increase the resilience of coastal settlements in the face of disaster risk (Abijith and Saravanan, 2021). Sometimes, sand mining becomes the primary cause of erosion and abrasion (Ranjith et al., 2019). The surrounding environment of the mine also suffers severe impacts on ecosystem sustainability. Environmental damage from mining activities can lead to significant ecological disturbances, detrimentally affecting the natural balance (Mngeni et al., 2016). The coastal areas in South Buton Regency, Indonesia exhibit environmental diversity and are vulnerable to changes, both physically and socio-economically. However, over the past five decades, there has been a change in the coastline due to sand mining activities, as land utilization practices such as sand mining along the coast have caused environmental damage, posing a threat to the livelihoods of coastal communities, especially in the coastal areas (Yunus, et al., 2023).

The Bandar Batauga Village, South Buton Regency, Indonesia has become the center of sand mining activities with two mining models on land and along the coastal areas. This activity has been ongoing for approximately 49 years. On the other hand, income from sand mining significantly contributes to the local economy despite facing serious environmental risks (Yunus et al., 2023). As a result, the region has experienced changes in the coastline and erosion caused by sand mining activities in the surrounding village (Yulianto et al., 2019). The change in the extent of erosion is significantly felt, particularly regarding the potential for natural disasters such as extreme waves and tsunamis (Regional Development Planning Agency of Southeast Sulawesi Province, 2021). Additionally, disaster mitigation and appropriate environmental management techniques are required to protect communities from natural disaster threats, especially in disaster-prone coastal areas (Alisyukur et al., 2020).

This research analyzed land changes in Bandar Batauga Village, Batauga District, South Buton Regency, Indonesia, known for its sand mining activities, leading to environmental degradation. Therefore, this research aimed to analyze land changes in disaster-prone coastal settlement areas, considering physical and socio-economic aspects, and predict coastal conditions until 2050 without mitigation. This research also aimed to assess the impact of sand mining activities on environmental conditions, especially those related to abrasion and coastline changes, along with evaluating policies and control efforts to reduce exploitation.

Materials and Methods

This research was conducted in Bandar Batauga Village, Batauga District, South Buton Regency, Indoensia (Figure 1), an area that experienced coastal environmental damage due to sand mining. This research employed a combination of quantitative and qualitative methods to gain a comprehensive understanding of land changes in disaster-prone coastal residential environments (Creswell, 2014). The quantitative approach was used to analyze coastline changes and predict erosion distances in 2050, while the qualitative approach was utilized to comprehend the social and cultural impacts of sand mining in coastal regions.

Data collection and analysis techniques

To obtain accurate data related to coastline changes in disaster-prone coastal settlements, a structured approach was employed through coastline change measurements using ArcGIS 10.3.1 software (Deabes, 2017) and 5-m digital transects for precise data acquisition. The baseline points were determined by considering the inland position adjacent to the coast, measured along the transect length from the coast to the baseline for each examined location (Khallaghi and Pontius, 2022). Additionally, in-depth interviews were conducted with relevant stakeholders, including landowners, miners, and local government officials, to collect economic data and understand the lifestyle patterns of communities involved in sand mining.

Data analysis was performed using both quantitative and qualitative approaches. ArcGIS 10.3.1 software was employed in quantitative analysis to analyze coastline changes and spatially map them. The subsequent steps involved calculating forecasts for future occurrences in 2050 using historical data through Single Moving Average (SMA) and Double Moving Average (DMA) techniques (Mustapa et al., 2019; Kusuma et al., 2021; Lukman and Tanan, 2021).

Single Moving Average (SMA)

The first step was calculating the average distance of shoreline change (m²/year) using SMA.

$$SMA_t = \frac{X_t + X_{t-1} + X_{t-2}}{3} \quad \text{.....(1)}$$

where:

SMAt	:	Average coastal line change distance for period t.
Xt	:	Area of abrasion in year t.
Xt−1	:	Area of abrasion in year t−1.
Xt−2	:	Area of abrasion in year t−2.
t	:	Time or period (in this case, years).
1/3	:	Smoothing factor for a 3-year period (1/3 represents the simple moving average).

The SMA value was used to predict the average distance of shoreline change in 2050 using the equation:

$$Prediction_{2050} = SMA_{2022} + (GrowthRate \times Period) \quad \text{..(2)}$$

Assuming a growth rate of 2% per annum over a 28-year period.

Double Moving Average (DMA)

In DMA, this study used two moving averages: SMA for trend and EMA for seasonality.

Trend of single moving average

$$SMA_t = \frac{X_t + X_{t-1} + X_{t-2}}{3} \quad \text{.....(1)}$$

Seasonal Exponential Moving Average (EMA)

$$EMA_t = \alpha \times X_t + (1 - \alpha) \times EMA_{t-1} \quad \text{.....(3)}$$

where:

EMAt	:	Exponential moving average for period t.
α	:	Weight given to the most recent value in EMA (in this case, 2α=0.2).
m	:	Multiplicative factor for EMA (m=2).

Prediction 2050 formula using DMA:

$$Prediction_{2050} = SMA_{2022} + m \times EMA_{2022} \ldots\ldots (4)$$

Descriptive statistics were applied to analyze economic data and coastline changes, followed by the Analytic Hierarchy Process (AHP) involving 12 key informants to assign weights to aspects, criteria, and alternative management strategies (Saaty, 2008; Deribew et al., 2022). The overall analysis was then formulated into strategic steps, encompassing policies and mitigation strategies based on in-depth interviews, literature reviews, and relevant documents.

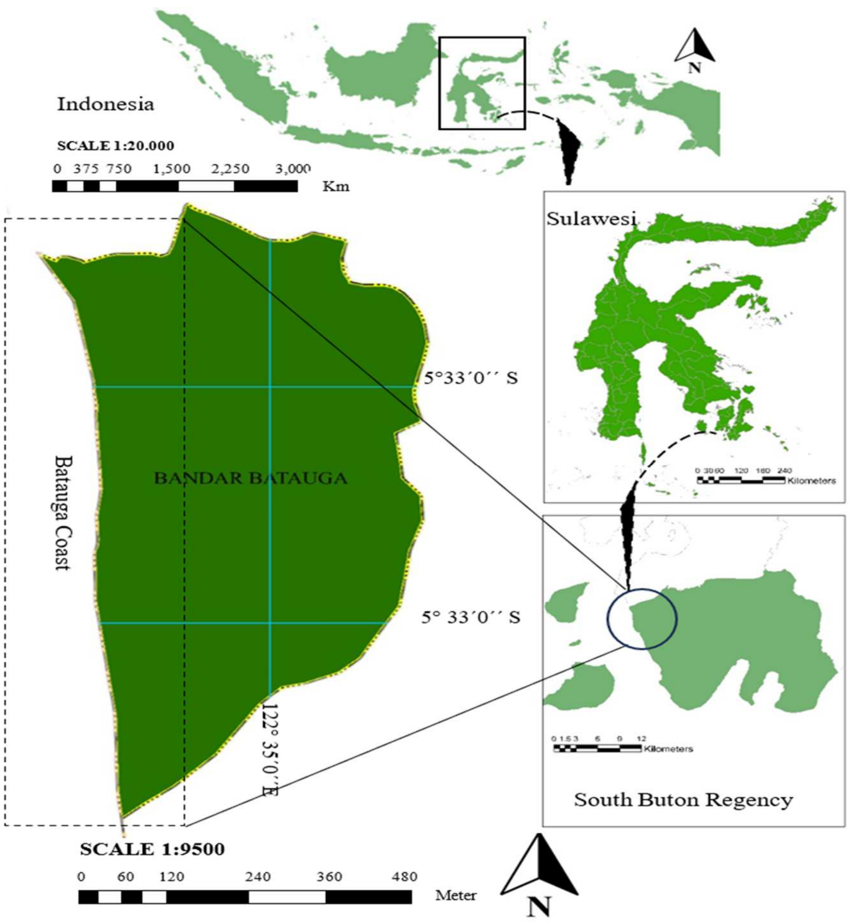

Figure 1. Administration map of Bandar Batauga Village, South Buton Regency, Indonesia.

Results

Bandar Batauga Village has two types of sand mining: on-land mining and coastal mining. This exploitative activity has been ongoing for quite a long time. Based on information from the community and relevant government authorities, mining activities have been taking place for 51 years, from the initiation of mining in 1972 until now. According to the annual analysis conducted by the South Buton Regency Government, specifically the Environmental Agency, it has been found that the area of sand land in Batauga has diminished by approximately 0.4 hectares. If estimated with 0.4 hectares x 12 months x 49 years, around 244.8 hectares of the total land area in Batauga have experienced erosion. This issue is very concerning when mining operations are not adequately monitored and managed. There is a possibility that, in the future, the entire coastal settlement area in Batauga will diminish due to erosion. Since a significant portion of the land in Batauga is composed of sand, the control and transition of livelihood sources other than mining must be promptly evaluated. The interviews with mining stakeholders revealed that, on average, the income of sand miners per month reaches up to 10 trucks. However, during government project seasons involving the construction of public facilities, the sand orders can exceed that amount. The selling price of sand per truck is approximately IDR 1.2 million. From this amount, the mine owner must pay IDR 300,000 for three transport workers and IDR 250,000 for sand miners. The remainder is allocated to the landowner, truck rental, and tax payments at the toll booth. In other words, sand mining yields a minimum monthly income of IDR 10 million for the community, providing without permits operating illegally. Illegal sand mining tends to increase and is challenging to control, especially with the growing market demand for Batauga sand. Observations from various informants indicate that infrastructure construction in South Buton

Regency and other commercial developments involves excavating hundreds of cubic meters of sand, leaving large holes in the mining locations. The sand mining center initially concentrated along the Bandar Batauga coast has expanded to include three villages: Busoa, Masiri, and Laompo. It has even extended to Sampolawa Subdistrict, adjacent to Batauga Subdistrict. The government continually implements approaches such as sanctions, warnings, mine closures, and persuasive methods. However, mining activities persist. This indication poses a challenge for the government to maintain supervision, provide guidance, and employ alternative approaches to reduce sand mining exploitation and mitigate disasters caused by reduced sand volume due to mining and erosion. This is in addition to the threats of landslides, tsunamis, and large waves resulting from the loss of natural vegetation that serves as a barrier and natural belt. The coastline changes in Bandar Batauga Village were assessed through Geographic Information System (GIS) analysis, with the analyzed data limited to the period between 2007 and 2022. The alterations in the coastline are presented in Figures 2, 3, and 4.

Figure 4 illustrates a fairly significant change in the coastline based on the analyzed coastline change data between 2007 and 2022. The coastline change distance in Bandar Batauga Village is approximately ±143.52 m², with an average coastline change distance of 50.8 m². The maximum area of coastline change is ±821.2 m², and the average area of coastline change is 159.19 m², indicating erosion occurs each year, as shown in the data provided in Table 1.

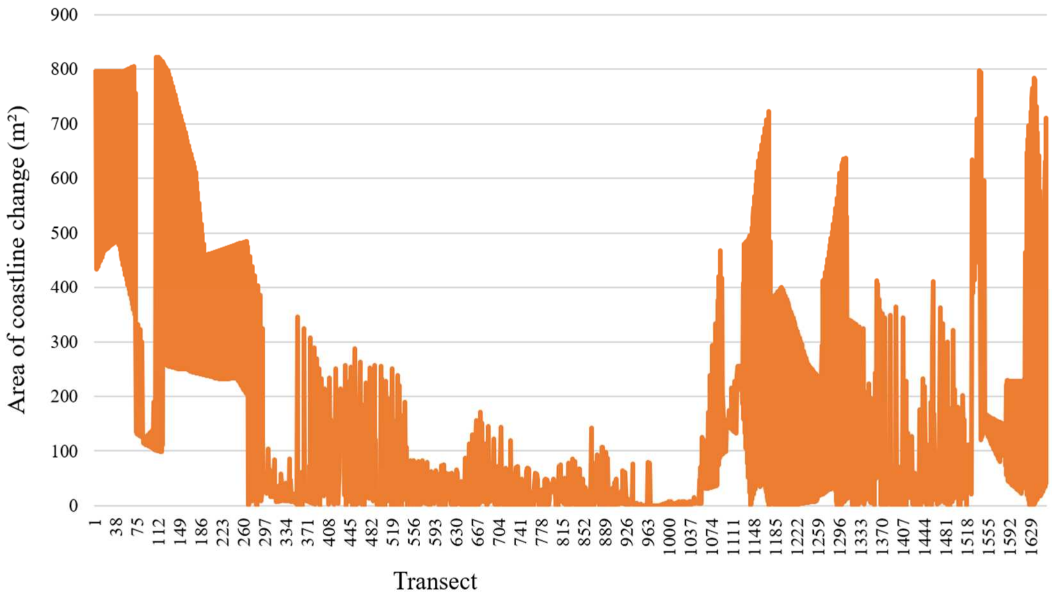

Figure 2. Distance of change of coastline.

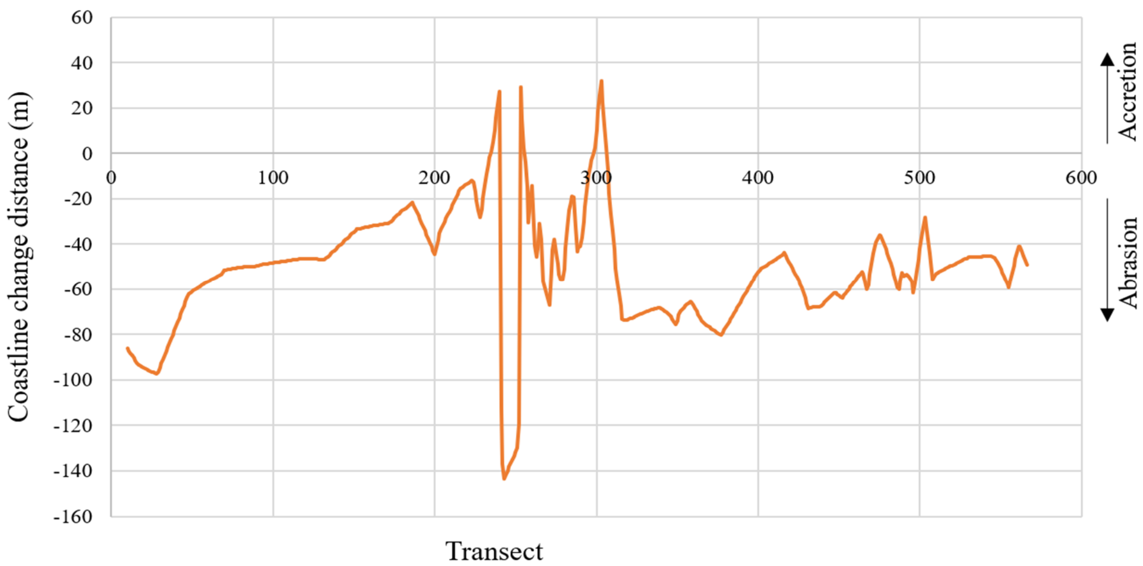

Figure 3. Area of abrasion.

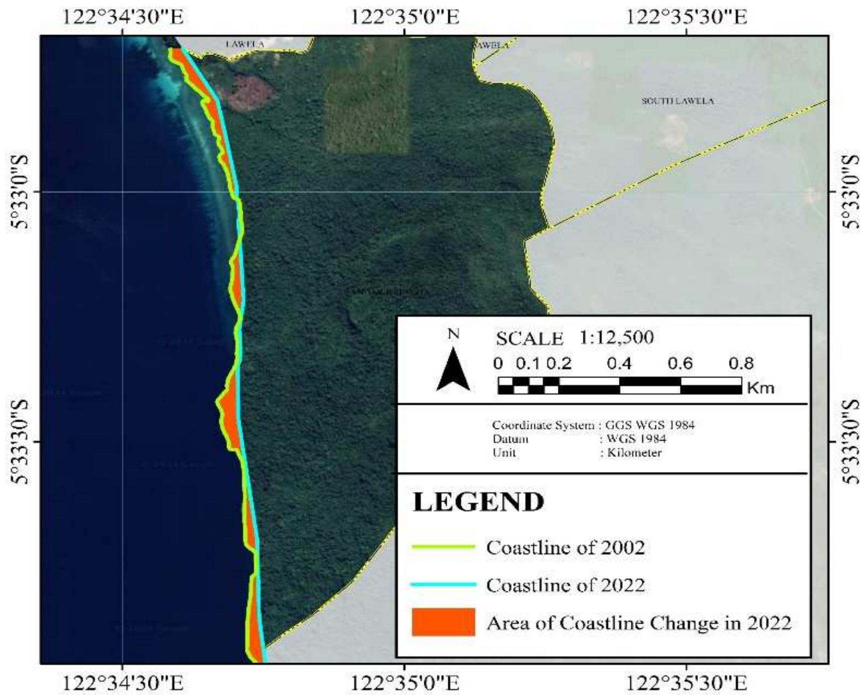

Figure 4. Map of coastline change in Bandar Batauga Village (base map source: Regional Development Planning Agency of Southeast Sulawesi Province, 2021).

Table 1. Land and coastline change.

No	Parameter	Historical Data	2050 predictions
1	Abrasion Area	2007: 124.5 m² 2022: 511.3 m²	1157.22 m²
2	Average Distance of Coastline Change (m²/year)	2007: 24.9 m²/year 2022: 102.3 m²/year	236.9 m²/year
3	Maximum Coastline Change Area (m²)	2007: 341.6 m² 2022: 821.2 m²	2463.6 m²

After performing forecasting calculations using the SMA/DMA technique, the forecasted values for the year 2050 for erosion area, coastline change distance (m²/year), and maximum coastline change area (m²) were obtained and presented in Table 2. After recapitulating using historical data, the following prediction graph obtained is presented in Figure 5. The data visualization then produces map images predicting changes in land and coastline due to sand mining activities from 1972 to 2022 and observations in 2050 presented in Figure 6. The changes in the coastal landscape in Bandar Batauga can pose dangers of erosion and ecological disasters for the surrounding areas along the coast, including large waves and tsunamis. In addition to the threats to the local community, erosion and natural disasters caused by sea waves also endanger public infrastructure such as hospitals, schools, and village offices, as indicated by the research findings showing average coastline change distances (m²/year), providing an indicator of the rate of coastal area changes over time. The data shows a consistent increase from 24.9 m²/year in 2007 to 102.3 m²/year in 2022, reflecting dynamic coastal changes that sand mining activities may cause. Changes in the coastal landscape are presented in Figure 7.

Table 2. Land and coastline change.

Year	Abrasion Area (m²)	Distance of Average Change of Coastline (m²/year)	Maximum Shoreline Change Area (m²)
2007	124.5	24.9	341.6
2012	234.2	46.8	477.9
2017	378.1	75.6	670.5
2022	511.3	102.3	821.2
2050	1,157.22	236.9	2,463.6

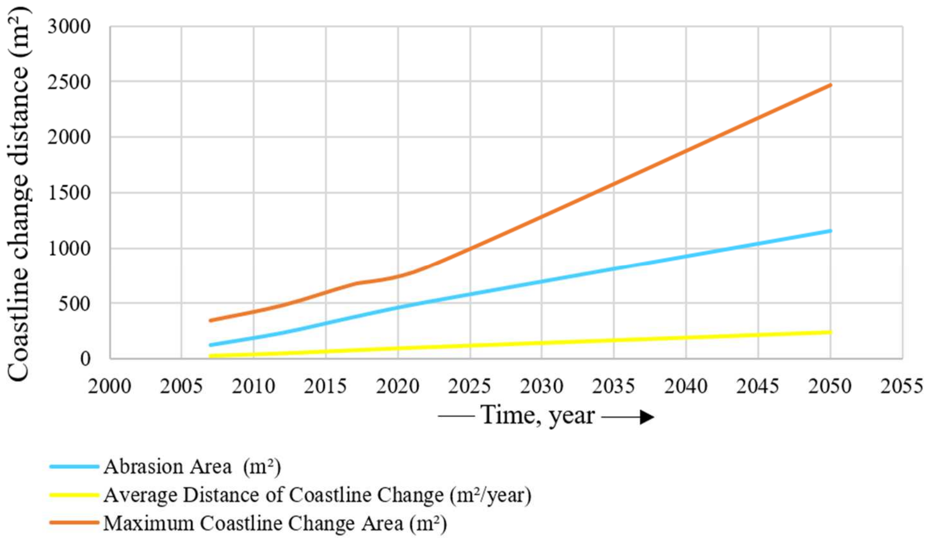

Figure 5. Forecasting of land and coastline changes.

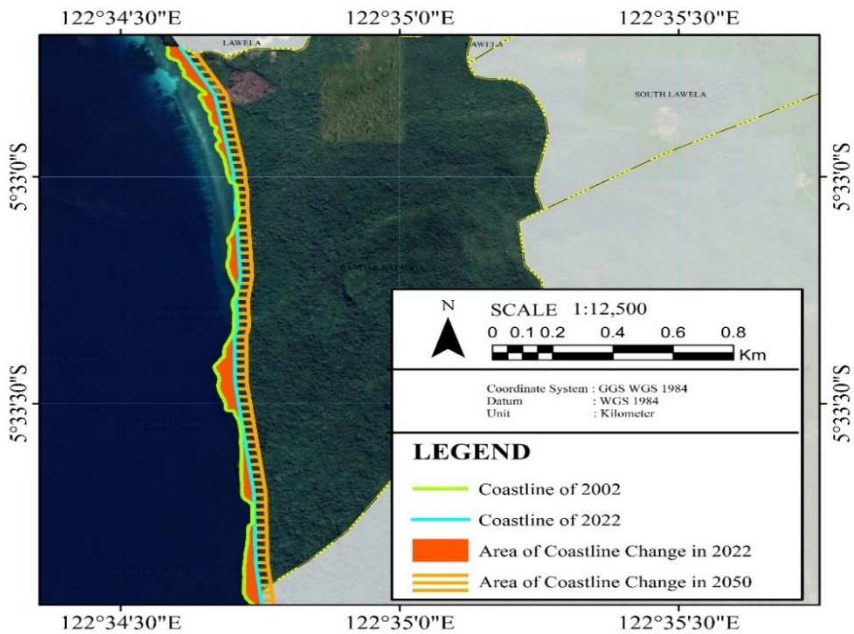

Figure 6. Land and coastline change forecast map for 2050 (base map source: Regional Development Planning Agency of Southeast Sulawesi Province, 2021).

Further analysis results regarding the prediction for the next 28 years indicate an estimated average coastline change distance of 236.9 m²/year by 2050. This indicates the continuation of significant coastline changes. Moreover, the maximum coastline change area increased significantly, from 341.6 m² in 2007 to 821.2 m² in 2022. Predictions using SMA and DMA project a maximum coastline change area of 2,463.6 m² by 2050, emphasizing the importance of understanding the general trends in coastline changes and the potential for extreme changes that can significantly impact coastal ecosystems and surrounding communities. Therefore, without preventive measures and appropriate steps to reduce mining activities, the possibility of settlements and public facilities collapsing cannot be ruled out. Thus, effective mitigation measures are necessary.

Implementation of management policies for disaster-prone coastal settlement environments

Overall, according to environmental management regulations, stone and sand miners have generally met the required conditions. The submission and preparation of environmental management and environmental monitoring efforts (UPL/UKL) for mining activities have been carried out in accordance with the provisions. However, in some cases, the fulfillment of obligations to control and improve environmental quality through the implementation of UPL/UKL is not entirely adequate. Particularly, environmental management policies in disaster-prone coastal areas are still below expectations.

Figure 7. The existing condition of the Batauga coast affected by sand mining activities (A) Abrasion due to mining, (B) Sand mining activities in coastal areas, (C) Former sand mine quarry puddles.

Several factors may contribute to this inadequacy. First, governance in related institutions and organizations and limited human resources remain obstacles despite the use of effective methods and the existence of a sufficiently educated workforce. Second, government services, especially in responding to reports and complaints from the public, are not optimal, with relatively slow response times. Additionally, although UPL/UPL documents provide clear policies, mining permit holders have not fully implemented environmental management measures. The implementation of mining activities is also under scrutiny. While the licensing process and other mechanisms have been well-established, their implementation has not been fully realized.

Repeated violations are also identified, including fatal errors indicated in UPL and UKL documents. Environmental management efforts, such as the reclamation of former mining areas, have not been optimally carried out to create and ensure environmental sustainability in the region. Furthermore, the lack of strict sanctions, such as closure and fines, in accordance with applicable regulations, is an important aspect that needs attention and improvement to enhance compliance and better environmental management.

Based on the description of the potential and issues of existing disaster conditions in the Coastal Area of the study location, the analytical hierarchy process (AHP) is used to formulate priority strategies in disaster mitigation in the coastal areas of the research location (Mappasomba et al., 2023; Rohaendi and Herlinawati, 2024). After processing the data by assigning pairwise comparison weights to aspects resulting from the perceptions of all informants, the results were obtained as shown in the analytical hierarchy process for various environmental aspects (Table 3).

The analytical hierarchy process (AHP) shows the interpretation of priority values in disaster management in coastal areas. Social, economic, and cultural environmental aspects place the highest priority on the protection of human life, followed by the protection of assets and infrastructure. Special attention is paid to coastal slums as an important factor. Meanwhile, Physical Environmental Aspects emphasizes shoreline preservation as the main focus, emphasizing sustainable management of sand mining. Seawater quality is also considered a factor that needs to be maintained.

Table 3. Process hierarchy analysis of various environmental aspects.

No	Aspect Criteria	Priority Value (%)
1	**Environmental, Social, economic and cultural aspects**	
	Preventing disaster victims	59.4
	Prevent material loss	24.9
	Preventing the emergence of coastal slums	15.7
Total Percentage		100
Data Inconsistencies		0.05
2	**Aspects of the Physical Environment**	
	Prevent shoreline changes	69.1
	Prevents excessive sand mining	21.8
	Prevent deterioration of seawater quality	9.1
Total Percentage		100
Data Inconsistencies		0.05
3	**Biotic Environmental Aspects**	
	Maintaining coastal vegetation	59.4
	Preventing the loss of marine life	24.9
	Preventing damage to coral reefs	15.7
Total Percentage		100
Data Inconsistencies		0.05

Note: Inconsistency values smaller than 0.1 indicate that the data is considered valid and accepted.

Biotic environmental aspects highlight the importance of preserving coastal vegetation as a key element in maintaining the balance of coastal ecosystems. Protection of marine life and coral reefs is also considered a priority in disaster management efforts in coastal areas. To provide an overview of the focus, rationale, and recommended strategies for improving coastal resilience to disasters, Table 4 presents the priorities, foundations, and policy strategies resulting from the analytical hierarchy process (AHP).

Discussion

The exploitation of natural resources, particularly sand mining in Batauga, is driven by economic interests and human needs. This mining practice, mainly conducted by the poor community since the 1970s, despite providing definite economic benefits, has caused environmental damage and the potential for natural disasters. Two mining models on land and along the coastal areas have been ongoing for almost fifty years. The lost land area due to sand mining reached 234.2 ha during this period. The impact of this exploitation is so significant that it raises concerns about the severe environmental damage that cannot be ignored in Bandar Batauga if mining is not wisely controlled. In this village, the prohibition of sand mining is not entirely effective. Coastal erosion and the reduction of sand volume in the coastal areas increase yearly. Significant changes in the coastline pose a severe threat to settlements and public facilities (Rumahorbo et al., 2022). This indicates the need for preventive actions and better environmental management strategies (Hanley et al., 2014; Ranasinghe, 2016).

Table 4. Disaster mitigation policy priorities and strategies.

No	Priority	Foundation	Policy Strategy
1	Social, Economic, and Cultural Environmental Aspects	Policies should be directed at protecting the population from the effects of disasters, reducing material losses, and preventing the formation of coastal slums.	– Effective implementation of evacuation and rescue plans. – Development of incentives and insurance programs to stimulate community participation in disaster risk mitigation. – Strict supervision of development and activities in disaster-prone zones.
2	Maintain Shoreline Stability	Policy strategies should be focused on preserving and maintaining shoreline characteristics.	– Establishment of coastal conservation zones involving vegetation and natural formations. – Regulation and close monitoring of sand mining activities. – Promotion of green technology to care for and restore damaged coastlines.
3	Natural Resources Management	In the context of AHP, maintaining coastal vegetation, marine life, and coral reefs is considered a priority.	– Development of coastal vegetation conservation programs through tree planting and ecosystem restoration. – Sustainable fisheries management and strengthening marine protected areas. – Establishment of protection zones for coral reefs and regular monitoring of ecosystem health.
4	Interagency Collaboration and Increased Sanctions	In the context of mining, cross-sector cooperation and strict sanctions need to be improved.	– Strengthening cooperation between government institutions, the private sector, and NGOs. - Regular audits and strict inspections of compliance with Environmental Management Efforts and Environmental Monitoring Efforts (UPL/UKL). – Drafting and implementing tougher sanctions, including temporary or permanent closure of violators.
5	Integrating Disaster Management Plans	Integration of disaster management plans needs to be an integral part of policy strategy.	– Establishment of rapid response teams for disaster management and rescue. – Development of an emergency response plan that involves active community participation. – Involvement of the private sector in mitigation and emergency response efforts.

Predictions using SMA and DMA models project the maximum change in coastline area to be 2,463.6 m² in 2050, emphasizing the importance of understanding the general trends in coastline changes, as well as the potential for extreme changes that can significantly impact coastal ecosystems and surrounding communities. Therefore, if there are no preventive measures and appropriate steps to reduce mining activities, the possibility of settlements and public facilities collapsing cannot be ruled out.

Given this situation, the government is faced with the challenge of addressing environmental degradation and changes in the coastal areas of Batauga that have been damaged. Preventive, precautionary, and protective measures must be applied, including serious law enforcement to control mining (Durga and Swetha, 2015). Conservation programs and ecotourism development are expected to be alternatives to increase local and regional income. Environmentally-based ecotourism development is expected to enhance socio-economic development without threatening the environment (Rohaendi and Herlinawati, 2024). The utilization of agricultural, fisheries, and former mining areas becomes a focus in efforts to improve the welfare of the local community (Kiper, 2013). Sustainable development with increased human resource capacity and program evaluation is expected to balance development and environmental preservation (Aticho et al., 2019).

An analysis of the implementation of environmental management policies in South Buton Regency shows several obstacles, including a lack of competence in related agencies, slow government response to reports and complaints from the public, and low awareness among mining permit owners. To overcome this, there is a need for an increase in human resource capacity, accelerated public services, and stricter enforcement of sanctions according to applicable regulations. Environmental management needs support from all governmental and non-governmental institutions. Consistent oversight, community participation, and control over sand mining must be enhanced (Akhmaddhian et al., 2023). Economic support and changes in the behavior of the local community are crucial to reducing environmental harm due to mining activities and improving sustainable well-being (Mancini and Sala, 2018).

Conclusion

The mining activities have caused significant changes in the coastline, resulting in erosion and posing threats to the environment and the socio-economic life of the community. By employing both quantitative and qualitative methods, this research identified substantial changes in the coastline from 2007 to 2022, projecting an abrasion area of 1,157.22 m² by 2050. This condition underscores the urgent need to mitigate the impacts of mining, including implementing stricter policies, enhanced supervision, and environmental conservation efforts. An analysis of the implementation of environmental management policies revealed challenges in law enforcement, inadequate government response to community reports, and a lack of awareness among mining permit holders. Preventive measures, strengthened environmental policies, and community-based conservation efforts are required to address these challenges. The focus should be preserving the coastline, managing natural resources, fostering inter-agency collaboration, and encouraging active community participation. These elements are crucial for achieving a balance between development and environmental preservation.

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