Coastal morphodynamic and assessments of coastal vulnerability index in Parepare bay

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Abstract. The purpose of the study is to assessments the coastal vulnerability index in the Parepare bay, the beach is Lojie area, District of Mallusetasi, Barru Regency, Lumpue and Lapakaka areas, District of Bacukiki, City of Parepare South Sulawesi Province with including some aspect that is morphodynamic, coastal characteristic, hydro-oceanography, and coastal vulnerability index. Geomorphology in the study area was grouped in the formation of the morphology of terrain, wavy, and hills. Stratigraphically is composed of Parepare Volcanic rocks (Tppv), and Alluvial Deposits (Qa), divided into 4 rock units namely alluvial units, trachyte unit, tufa unit, and volcanic breccias. unit. Based on that, coastal characteristic in research area divisible in 3, that is rock coastal, sandy coastal and mud/mangrove coastal. Hydro-oceanography condition in research area that is about current with velocity of current average is 0.191 m/s with direct current is N 97° E (southeast), wave with average of high wave velocity of current average is 0.191 m/s with direct current is N 97° E (southeast), wave with average of high wave is 56.40 cm, velocity of wave is 2.4 m/s and wave maximum energy as big as 10368 joule, tide subsides in research area with high tide 1.3 meters and low subside is 0.6 meters with sea-level high 1 meters. Coastal morphodynamics and vulnerabilities of the Parepare Bay on the northern part of Lumpue Coastal, which was dominated by sand-sized sedimentary material, found multiple bars due to low/weak energy wave activity, sloping beach morphology, and predominantly residential areas. It is thus categorized as a dissipative type beach with a low level of vulnerability (CVI = 6). As for the south of the study area, the Lapakaka Coastal and Lojie Coastal are dominated by gravel and coarse-sized sedimentary material, found coral reef fragments due to high energy wave activity and mangrove found in coastal areas. Then this beach can be classified in the type of reflective with a high level of vulnerability (CVI = 53.66 n 37.94).

1. Introduction

The beach is part of a diverse area, easily changes shape and becomes resilient to natural processes and human activities [1]. One of the important beaches uses is as a residential area, where more than 70% of the world's major cities are on the coast. This is closely related to the potential of the beach that has visual appeal, in addition to other potentials of the coast as residential areas, aquaculture, ponds, agriculture, ports, tourism [2]. Besides that, the beach is also prone to destructive wave and tsunami actions.

Coastal areas place of various pressures and developments and changes. The framework encourages all parties to carry out coastal planning and management according to their natural conditions and...
must be oriented towards saving the ecosystem environment. Coastal areas increasingly face high pressure from natural activities of coastal dynamics including winds and waves that have an impact on landscape dynamics [3]. In addition, coastal areas also receive various impacts caused by human activities, for example, building loads and large-scale extraction of groundwater which causes land subsidence [4,5]. By identifying coastal areas that are vulnerable to erosion and disasters, local governments can reduce the risk of impact impacts in an effective manner [6]. To know the vulnerability of the beach in Parepare Bay, South Sulawesi Province, it is necessary to conduct a study with coastal vulnerability analysis. Based on the results of the vulnerability analysis can be found alternative handling of coastal damage that occurred. Administratively, the research area is included in the Parepare Bay area which includes the Lojie Area, Mallusetasi District, Barru Regency, and Lumpue Area, Bacukiki District, Parepare City, South Sulawesi Province.

In 1998, Arthurton from the British Geological Survey has proposed several recommendations which include action to reduce coastal vulnerability as a way of mitigating marine and coastal natural disasters in the Pacific. The assessment of coastal vulnerability is an important initial requirement in determining high-risk coastal areas.

As for coastal morphodynamics, it contains an understanding of the relationship between forms, processes and other parameters that can change the shape of the coast. Influential variables can be in the form of waves, sediment material size, coastal slope and secondary wave phenomena [7]. The concept of coastal morphodynamics has been widely accepted in coastal engineering literature since its introduction in the mid-1980s and expanded in the 1990s, where it is emphasized that geological factors are important limits in determining the level of the coast actually, consisting of coastal forms that are limited to the evolution of morphology and origin of the coastal material [8].

Coastal morphological diversity in time units with the strength of hydrodynamic changes in the form of waves and tides, is a spatial change in coastal morphology as a response to geographic variations in an environmental condition in the form of waves, tides, coastal sediments, geology and other factors [9]. Especially for the role of geology most often mentioned as an important factor in controlling coastal morphology, such as the presence of outcrops or coral reefs, the size of sediment material and their availability.

Changes in the shape of the coast based on morphodynamics is an important study in analyzing coastal vulnerability so that the linkages between the two become the main focus in this study. Furthermore, it is outlined in the form of a coastal vulnerability index map.

2. Geological of the study area

Geomorphology in the study area was controlled by the existence of volcanic activity in the past, and the denudation process that occurred in the formation of the morphology of terrain, wavy, and hills in the study area as shown figure 1.

The research area is composed of Parepare Volcanic rocks (Tppv), and Alluvial Deposits (Qa). Based on lithological characteristics and field features mapped on a scale of 1:10,000, the study area is divided into 4 rock units namely alluvial unit, trachyte unit, tufa unit and volcanic breccia unit as shown in figure 2 and figure 3.

![Figure 1](image-url)

*Figure 1. Morphology unit of pyroclastic hills (x), morphological units of pyroclastic plain (y) and fluvial land (z) photographed with the direction of N97°E in the Bojo area.*
From the results of rock microscopic analysis for trachyte, brown absorption colour, showing black interference colour, hypo crystalline crystallinity, porphyritic granularity (porphiroafanitic), anhedral–euhedral mineral form, mineral size <0.02–1.20 mm, mineral composition consisting of plagioclase, oligoclase, hornblende, biotite, quartz and groundmass as shown in figure 4.

The alluvial unit is composed of lumps of rock that come from igneous rocks, but sometimes there are also other rocks such as volcanic breccia but in very small quantities, the rest is sand-sized to clay, but this sand material is dominated by sand-sized material very coarse. The comparison group is the Qac group (alluvium, lake and beach deposits) composed of clay, silt, sand and gravel components along the large river as shown in figure 5. Many coral fragments were also found as shown in figure 6.
Based on the geological map made in 1982 the Parepare area was affected by the Walanae regional fault which was northwest-to-southeast and was active which had an impact on rock deformation in the form of folds, joint, and faults. The geological structure found in the study area is in the form of folds and joints. In the study area, rock position was measured on volcanic breccia lithology, fine tuffs, which showed a similar position to the relative distribution from the Southeast-Northwest direction.

3. Coastal characteristics
The study of coastal systems evolution is an important issue for proper coastal management and the planning of sandy beaches. For this reason, it is often recommended the use of the morphodynamic classification of the beach system in order to forecast changes in beach morphology, when dealing with coastal management. The classification should be based on the mutual interaction of all hydrodynamic and morphological parameters (i.e. wave climate, mean grain size, beach shape) in order to provide a complete description of the physical processes occurring in coastal areas and affecting the beach response.

Regionally, the study area located Sulawesi Island in the center of the Indonesian archipelago, formed by the accumulation of microplates derived from a variety of sources such as fragments of Asia, Pacific and Australia. Since its formation in the Tertiary period to the present, it consequently produces continuous complex geological and tectonic phenomena. Due to the insistence of influence/pressure on the three major plates, it becomes a very vulnerable condition and includes one of the most active islands in the world.

The research area is located in the southern part of Parepare in the Lumpue Coastal Area and the northern part of the city of Barru are on Lojie Coastal and Lapakaka Coastal. The following is a discussion about the characteristics of each of these beaches.

3.1 Lumpue coastal
Around the Lumpue coastal is an area composed of volcanic rocks and igneous rocks and part of the coast is composed of sedimentary material in the form of sand and gravel deposited from the Bojo River and Karajae River.

In general, Lumpue coastal conditions are divided into primary coastal where the process takes place from sedimentation of rivers and rocks around the coast. The concave beach shape towards the sea is formed by igneous and volcanic rocks and parallel to the sea formed by deposition at the mouth of the river. Around the coast of Lumpue is an area composed of volcanic rocks and igneous rocks and part of the coast is composed of sedimentary material in the form of sand and gravel deposited from the Bojo River and Karajae River. By petrography analysis using a thin section, the beaches are composed of quartz, orthoclase, biotite, volcanic glass, clay mineral, and fossil. The occurrences of volcanic glass show that sediment material of coastal sourced from Parepare volcanic rock as shown in figure 7.

![Photomicrograph of a thin section of fine sand, show occurrences of (a) orthoclase (b) fossil (c) clay mineral (d) biotite (e) volcanic glass.](image-url)
The results of data processing for sediment texture showed that Lumpue Coastal consists of gravel 0.7%, sand 75.9% and mud 23.48% as shown in figure 8. Most of the sediment material derived from Karajae River and Bojo River.

![Graph showing grain size distribution](image)

**Figure 8.** The data processing results diagram for sediment texture of Lumpue coastal.

This area is classified as rocky beach, which is a beach that has a meandering morphology, which generally has a rock structure that is hard to withstand the impact of waves, which has a small impact on the shore, characterized by pyroclastic rock outcrops and igneous rock trachyte with Lumpue caldera and quaternary coral reefs.

### 3.2 Lapakaka coastal

Lapakaka Coastal is an area located in Bojo Village, Mallusetasi District, Barru Regency, South Sulawesi Province. Around the coast of Lapakaka is an area composed of sedimentary material in the form of sand, and gravel from the Bojo River as shown in figure 9. In this area, it is used as a residential area, and several buildings are used in business and as tourist attractions. Along coastal, it is also built of the embankment to prevent seawater from overflowing into residential areas during high tide as shown in figure 10. In general, the condition of the Lapakaka Coastal is classified into the primary coast where the process that takes place comes from river sedimentation. The shape of the beach is parallel to the sea formed by sedimentation in the river mouth.

![Sediment material in Lapakaka coastal](image)

**Figure 9.** Sediment material in the form of sand and gravel on the Lapakaka coastal.

![Embarkment in Lapakaka coastal](image)

**Figure 10.** The embankment that is functioned as a wave barrier is photographed in direction N7°E.
The results of data processing for sediment texture showed that Lapakaka Coastal contains gravel 41.3%, sand 58.6% and mud 0.1% as shown in figure 11.

![Figure 11](image1.png)

**Figure 11.** The data processing results diagram for sediment texture of Lapakaka coastal.

This area is classified as a sandy beach which is a low relief morphology with the type of material is sand. Sand particle size on the beach is a function of the wave movement on the beach if the particles are small, the wave motion is small, if the particles on the beach are large then the waves in the area also form large gravel deposits.

### 3.3 Lojie coastal

This coastal area located in Lojie Village, Mallusetasi District, Barru Regency, South Sulawesi Province. The geographical location of Lojie Beach is directly facing the Makassar Strait and is located about ± 4 km to the south of the Lumpue beach. The areas that were passed throughout the study area were Bojo and Lojie areas. Around the coast of Lojie is a swamp area that is overgrown with mangroves as shown in figure 12, and is composed of sedimentary material in the form of coral sand and part of the coast consists of sedimentary material in the form of clay, silt, mud, sand, and sedimentary gravel from the Bojo River. In general, the condition of the area is divided into the primary coastal where the process takes place from the river sedimentation as shown in figure 13.

![Figure 12](image2.png)

**Figure 12.** The sediment produced by the river at the mouth of the Bojo River was photographed in the direction of N272°E.

![Figure 13](image3.png)

**Figure 13.** The appearance of the type of mangrove Rhizophora Stylosagriff at Lojie Beach was photographed in the direction N96°E.
The results of data processing for sediment texture showed that Lojie Coastal contains gravel 0%, sand 44.0% and mud 56.0% as shown in figure 14.

Figure 14. The data processing results diagram for sediment texture of Lojie coastal.

The type of beach in this area is dominated by mud material, found swamp areas that are overgrown with aquatic plants, and some are mangrove plants.

4. Hydro-oceanographic data

The average current velocity obtained is 0.191 m/s with an average current direction of N 97°E (south-eastern east). Current is the main driving force of water circulation and sediment material where the greater the flow velocity, the greater the size of the sediment grain produced on the coast. Current activity in transporting sediments will depend on the wave energy that works along the coast. In the deeper waters, the current acts to erode and transport the suspension material to be distributed to the waters.

Waves above sea level are generally formed due to the process of flow of energy from the wind to the surface of the sea. The waves approaching the beach experience refraction. Sea wave data can be obtained by taking direct measurements in the field. Based on the processing of wave data, the average wave height range is 56.40 cm, the average wave velocity is 2.4 m/s and the maximum wave energy is 10368 joules. Sediment material allows it to be moved by wave power over a long time span.

The results of tidal measurements in the study area indicate the highest tide is 1.3 meters with the lowest tide is at 0.6 meters and the sea level is 1 meter as shown in figure 15.

Figure 15. Tidal graph of the research area.
5. Coastal morphodynamic and assessments of coastal vulnerability index

The discussion of the coastal morphodynamics of the study area covers many aspects, especially geological data as the main support in analyzing morphodynamics. In this case, it refers to the results of previous research that researchers have conducted as well as from supporting journals. The research stated that the main geological influence that controls is the size of sediment and its presence, so in this case, the presence of outcrops or coral reefs should be taken into account in addition to of course the hydrodynamic factors, especially waves. Thus, it can be said that the wave conditions are also tidal, sediment size characteristics and the role of geology can significantly influence and control the coastal morphology. Based on these factors, a coastal classification was made which then became a reference in this study as shown in figure 16.

![Figure 16. Conceptual morpho dynamic framework (within-RTR space) proposed.](image16)

The results of processing data on coastal sediment samples show a variable parameter value for the sediment grain size varies. These different values certainly indicate the variation in grain size, distribution, and conditions of coastal hydrodynamics that work in the research area, so that analysis of the morphodynamics of the coast can be carried out.

![Figure 17. Coastal vulnerability zone map of Pare-pare bay.](image17)
The coastal vulnerability analysis of the study area is based on the Coastal Vulnerability Index (CVI) proposed as shown in table 1 and table 2. In this study the coastal vulnerability index was calculated using the equation:

\[ CVI = \sqrt{\text{multiplication of all variables/number of variables}} \] (1)

**Table 1.** Coastal vulnerability index (CVI) physical variable.

| No | Variable                        | 1            | 2                        | Quality                      | 4                        | 5                        |
|----|---------------------------------|--------------|--------------------------|------------------------------|--------------------------|--------------------------|
| 1  | Shoreline Changes (PP)          | 0 m/yr       | (0-1) m/yr               | (1-5) m/yr                  | (5-10) m/yr              | >10 m/yr                 |
| 2  | Visual Damage Observation (K)   | There is damage seen | There is a shear zone seen but still stable | There is a shear zone and will be a collapse | There are a shear zone and collapse but not dangerous for infrastructure | There is a shear zone and collapse and dangerous for infrastructure |
| 3  | Damage Length (PK)              | < 0.5 km     | 0.5 – 2.0 km             | 2.0 – 5.0 km                | 5.0 - 10 km              | > 10 km                  |
| 4  | Damage Width (PK)               | 0 m          | 1-10 m (1000-1500) m     | 10-50 m                     | 50-100 km                | > 100 m                  |
| 5  | Green Belt Width (SH)           | > 1500 m     | Rocks Igneous Rock, Sedimentary rocks fine grain, massive and soft | Gravel and coarse grain, little bit massive | Sand, silt, clay, little bit massive | Sand, silt, clay, mud, consolidate |
| 6  | Lithology (L)                   |              |                          |                              |                          |                          |
| 7  | Wave Height (H)                 | < 0.5 m      | (0.5-1) m                | (1-1.5) m                   | (1.5-2) m                | > 2 m                    |
| 8  | Tidal Wave Range (PS)           | < 0.5 m      | (0.5-1) m                | (1-1.5) m                   | (1.5-2) m                | > 2 m                    |
| 9  | Land Using (PL)                 | Moor, Mangrove, waste land and swamp | Domestic tourism place and fish pond | Rice field and intensive fish pond | Settlement, harbour, office, school, province main road | Preserve culture area, desitize domestic tourism, industrial district, country main road |
| 10 | Coastal Slope                   | 0-2 %        | 2.5 %                    | 5-10 %                      | 10-15 %                  | > 15 %                   |

**Table 2.** Level of vulnerability based on CVI

| CVI | Vulnerability Level |
|-----|---------------------|
| 0-25| Low                 |
| 25-50| Middle             |
| 50-75| High               |
| >75 | Very high          |

Based on physical appearance and measurement results in addition to the processing of coastal sediment data, shoreline changes and field observations, the diversity of CVI values obtained for each research area as shown in table 3 and table 4.
Table 3. Assessment variables of coastal vulnerability index.

| No | Physical Variables     | Lumpue Coastal | Lojie Coastal | Lapakaka Coastal |
|----|------------------------|----------------|---------------|------------------|
| 1  | Shoreline Changes      | 3              | 3             | 3                |
| 2  | Visual Damage Observation | 1          | 4             | 4                |
| 3  | Damage Length          | 1              | 2             | 2                |
| 4  | Damage Width           | 1              | 1             | 2                |
| 5  | Green Belt Width       | 4              | 5             | 5                |
| 6  | Lithology              | 5              | 5             | 5                |
| 7  | Wave Height            | 2              | 2             | 2                |
| 8  | Tidal Wave Range       | 3              | 3             | 3                |
| 9  | Land Using             | 1              | 4             | 4                |
| 10 | Coastal Slope          | 1              | 1             | 1                |
|    | Score Total            | 22             | 30            | 31               |
|    | CVI                    | 6              | 37.94         | 53.66            |

Table 4. Vulnerability level

| CVI | Lumpue Coastal | Lojie Coastal | Lapakaka Coastal |
|-----|----------------|---------------|------------------|
| Low |         | Middle        | High             |

Coastal morphodynamics and vulnerabilities of the Parepare Bay can be grouped based on the results of processing sediment sample data, hydrodynamic data, coastal characteristics and the level of coastal vulnerability. The research location on the northern part of Lumpue Coastal, which was dominated by sand-sized sedimentary material, found multiple bars due to low / weak energy wave activity, sloping beach morphology, and predominantly residential areas. It is thus categorized as a dissipative type beach with a low level of vulnerability. As for the south of the study area, the Lapakaka Coastal and Lojie Coastal are dominated by gravel and coarse-sized sedimentary material, found coral reef fragments due to high energy wave activity and mangrove trees found in coastal areas. Then this beach can be classified in the type of reflective with a high level of vulnerability.

6. Conclusion

Geomorphology in the study area was controlled by the existence of volcanic activity in the past, and the denudation process that occurred in the formation of the morphology of terrain, wavy, and hills. Lithology units divided into 4 rock units namely alluvial unit, trachyte unit, tufa unit, and volcanic breccia unit. Coastal morphodynamics and vulnerabilities of the Parepare Bay at the northern part of Lumpue Coastal it is categorized as a dissipative type beach with a low level of vulnerability. As for the south of the study area, the Lapakaka Coastal and Lojie Coastal are can be classified in the type of reflective with a high level of vulnerability.

Acknowledgments

The author is grateful to my institutes which has provided motivation and support in the preparation of this journal. We would also like to thank Kaharuddin, Namrullah, and the student also assistance at the Department of Geology for help in the field and data processing. This study is contributed to the research in Geology Engineering Hasanuddin University and for scientific progress.
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