https://jurnal.unimed.ac.id/2012/index.php/geo/article/view/45225
https://doi.org/10.24114/jg.v16i1.45225 - (Vol 16, No 1 – 2024)
available at http://jurnal.unimed.ac.id/2012/index.php/geo
e-issn (2549-7057) & p-issn (2085-8167)

Tsunami Vulnerability Analysis Based on Coastal Typology in the Coastal Area of Ende City

Maria Theresia Firmina Baru[1,2], Djati Mardiatno [3*], Muh. Aris Marfai [4,5]
[1]Department of Geography, Faculty of Geography, Universitas Gadjah Mada Yogyakarta, Indonesia
[2]Government Staff Kabupaten Ende, Nusa Tenggara Timur, Indonesia
[3,4]Department of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada, Indonesia
[5]Geospatial Information Agency (BIG), Indonesia

ARTICLE INFO
Article History:
Received: May 02, 2023
Revision: January 20, 2024
Accepted: January 26, 2024

Keywords:
Coastal City of Ende
Coastal Typology
Tsunami
Susceptibility
Land Use

Corresponding Author
E-mail:
djati.mardiatno@ugm.ac.id

ABSTRACT
Ende City has a threat of tsunami disaster. Ende City's coastal area management policy regarding disaster mitigation needs to consider coastal typology. Efforts to reduce the risk of tsunami must pay attention to the physical development of coastal land so that the coastal resource is maintained. Therefore, the aim of this research was to analyze the level of tsunami susceptibility based on coastal typology in the coastal area of Ende City. The methods used in this research are survey and spatial analysis.. The survey results were compared with literature studies to determine coastal typology and determine land use. Spatial analysis is carried out using overlay, scoring and weighting techniques to produce tsunami susceptibility levels. Geospatial parameters to determine the level of susceptibility are topography, distance from the coastline, slope, distance from rivers and coastal morphology. Susceptibility analysis is carried out for each coastal typology, because each coastal typology has a different response to tsunami. The results of the research show that there are five classes of tsunami susceptibility, namely very susceptibility, susceptibilty, somewhat susceptibility, safe and very safe. Very susceptibility areas are marine deposition coast typology, anthropogenic coast typology and sub area deposition coast typology. The safe areas are wave erosion coast typology and volcanic coast typology.

INTRODUCTION

The population density in coastal areas is due to their dynamic nature, complex, multi-functional environment, and unique value. Ecological diversity and characteristics of coastal habitats are essential to sustain coastal dynamics and provide various ecosystem services necessary for human well-being (Rodrigues et al., 2017). Ecosystems and settlements are most vulnerable to coastal disasters such as tsunamis. Therefore, coastal susceptibility needs to be identified to determine the possibility of potential disasters occurring on the coast.

In analyzing the level of disaster susceptibility, it is necessary to study the physical processes or genesis of the coast. According to (Sunarto, 2004) genesis, the study refers to geomorphological processes in coastal areas. Geomorphological processes in coastal regions study landforms with greater emphasis on the characteristics, origin and development of landforms. Wind, wave, current and tectonics are the forces that drive geomorphological dynamics in coastal areas (Sunarto et al., 2014). The landform or morphology of the coast, which has characteristics called typology, will influence the response of the coast to disasters. Each coastal typology has its characteristics of coastal formation processes and dynamics (Mutaqin et al., 2019). Geomorphological studies will produce data/information regarding the physical landscape, which will become primary data in regional development planning and coastal management (Marfai et al., 2013; Sugiyanta, 2014).

The study of coastal typology in the coastal area of Ende City refers to the division of typology according to (Shepard, 1972; Pethic, 1984). The typology of the coastal regions is grouped based on their genesis, namely primary coasts and secondary coasts. Primary coasts are influenced by land or terrestrial processes. Primary coasts consist of sub-aerial deposition coast typology, land erosion coast typology, volcanic coast typology, and structurally shaped coast typology. Secondary coasts are influenced by marine activities such as sediment activity and sea waves. Secondary coasts consist of wave erosion coast typology, marine deposition coast typology and coast built by organism typology. (Gunawan, et al., 2007; Marfai & Cahyadi, 2012) stated that coastal typology is closely related to the type, characteristics and susceptibility of disasters that occur on a coast. Coastal characteristics have different typologies and complex coastal dynamics.

One of the potential disasters that occur in the coastal areas of Ende City is the tsunami disaster. The tsunami threat to Ende City is because Ende City is located on Flores Island, East Nusa Tenggara Province, which is in the zone of movement of the Indo-Australian plate towards the Eurasian plate. This condition causes the Ende City area to have relatively high levels of seismicity, land movement, and landslides and is susceptible to tsunamis (Ndeo et al., 2017). The tsunami disaster that hit Flores occurred in 1814 and 1992. The tsunami disaster that occurred in 1992 resulted in property damage and the loss of life to thousands of people. The tsunami originated from an earthquake with a magnitude of 7.5 on the Richter scale (Ndeo et al., 2017). Apart from that, Ende City has an active volcano, namely Mount Iya. The volcanic activity makes the coastal areas of Ende City susceptible to tsunamis.

Volcano Iya last erupted in 1969, which caused the eruption of hot clouds, rocks (lapilli and volcanic bombs), sand and ash, most of which fell in the southern and western parts of Volcano Iya (Sutawidjaja, 2011). If Volcano Iya erupts again, it could cause a tsunami in the coastal areas of Ende City. The tsunami in the coastal area of Ende City was caused by kinetic energy pressing on seawater. According to Sutawidjaja, 2011, tsunamis caused by kinetic energy can reach a height of 10 meters and damage buildings and infrastructure along the south coast of Ende Regency (east and west coast of Ende City) (Mutaqin et al., 2019).

Data from the National Disaster Management Agency, the Ende Regency tsunami disaster risk index is in class 12.72 with a high-risk class (BNPB, 2020). Historical data indicates that there is a tsunami threat to Ende City. Efforts to mitigate the tsunami disaster were carried out by studying the level of tsunami vulnerability in the coastal areas of Ende City. A study of the level of tsunami vulnerability is carried out for each coastal typology, considering that differences influence disaster potential in coastal typologies and typological responses to tsunamis. Therefore, this research aims to analyse the level of vulnerability to tsunami disasters using geospatial parameters based on coastal typology in the coastal area of Ende City. This research can be a policy recommendation for the Ende district government in managing coastal areas based on aspects of coastal landform development. The originality of this research, which can be distinguished from other research, is the coastal typology as a unit of analysis of tsunami susceptibility. Differences in typology are a determining factor in the direction of disaster mitigation strategies. Analysis of tsunami disaster susceptibility seen from the genesis and changes in coastal physical landforms, namely typology, will be more effective and comprehensive in efforts to mitigate and preserve coastal natural resources.

RESEARCH METHODS

Time and Location of Research.

This research was carried out from October 2021 to December 2021. This research was conducted in the coastal area of Ende city, Ende district, East Nusa Tenggara province, which is at coordinates 8°39' – 8°54' South Latitude and 121° 37'–121° 42' East Longitude, with a coastal area of 28,907,386 m². The coastal area of Ende City studied includes eight sub-districts and two villages, namely Kota Raja sub-district, Kota Ratu sub-district, Mbongawani sub-district, Rukun Lima sub-district, Paupanda sub-district, Tanjung sub-district, Tetandara sub-district, Mautapaga sub-district, Nanganesa village and Manulando village. The coastal area of Ende City, which is the research study area, can be seen in Figure 1.

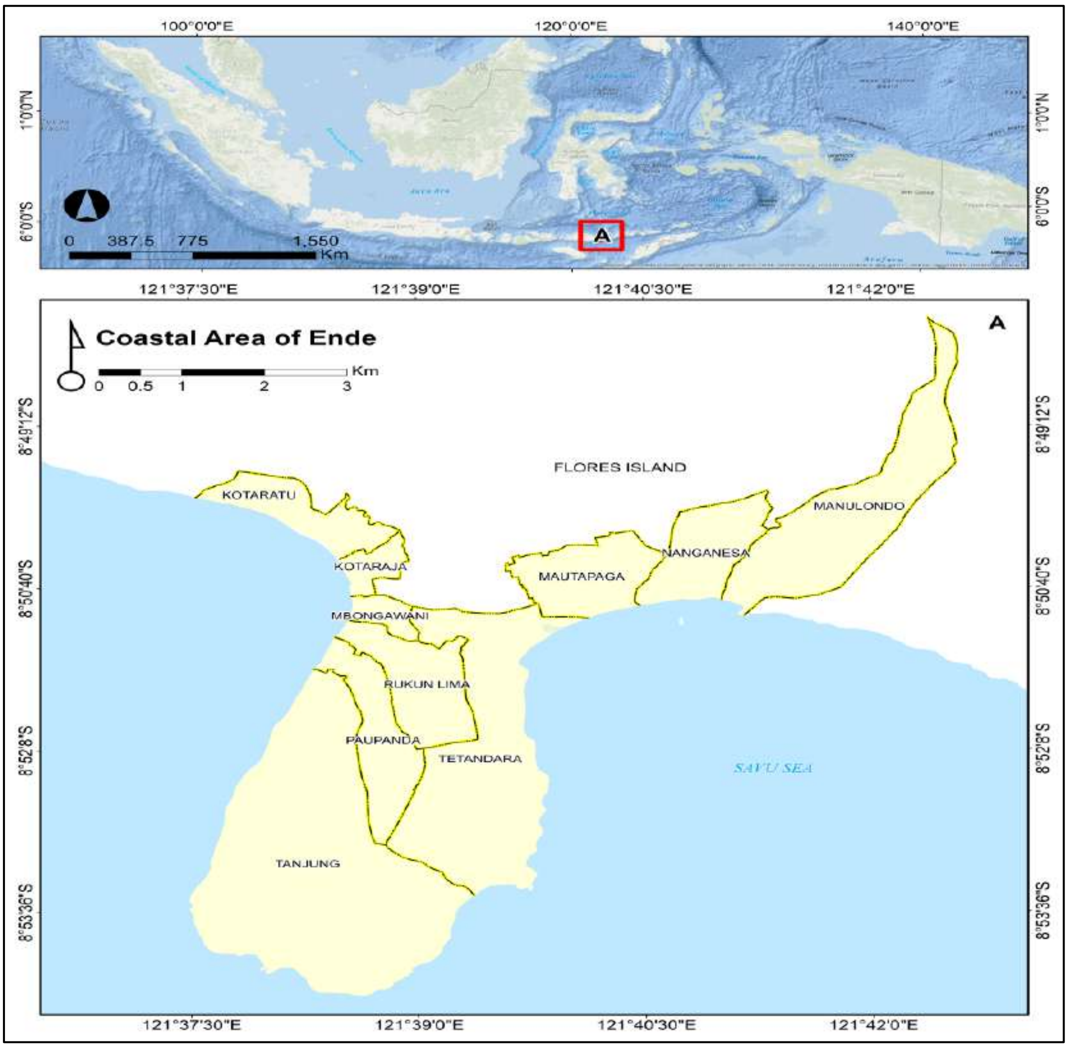

Figure 1. Research Area Map (Source: Analysis of Research Results, 2021)

The coastal area of Ende City is an urban area, government centre, and economic and trade centre, with plans to develop natural tourism. The concept underlying this research is that issues in the coastal area of Ende City are resolved using a comprehensive approach that combines geomorphological process studies regarding tsunami disaster vulnerability and landform changes traced from typology studies. The results of the analysis of tsunami disaster vulnerability in each coastal typology became the basis for developing a management strategy for Ende City's coastal areas. The research framework can be seen in Figure 2.

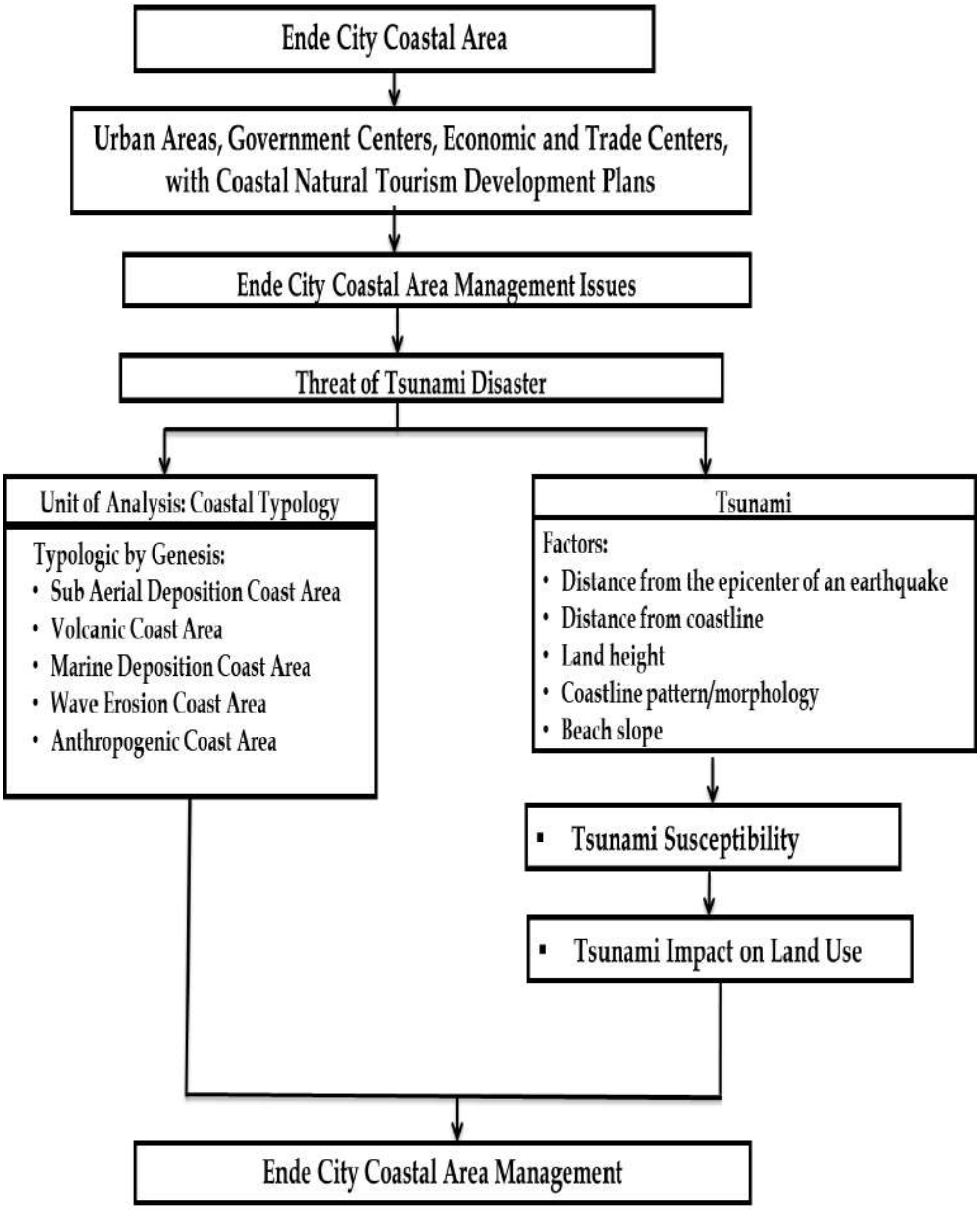

Figure 2. Schematic of the Research Conceptual Framework.

Tools and Materials.

The tools used in this research can be seen in the table 1.

The materials used in this research are seen in Table 2.

Table 1. Tools Used in Research.

No	Tool	Information
Hardware		
1	Laptop	For data processing, presenting results and preparing research results reports.
2	Soni A 6000 Camera	To get images of field survey results
3	GPS	Measuring transect lines
Software		
4	Arc Gis 10.6	For spatial analysis

Table 2. Materials Used in Research.

No	Material	Source	Information
1	High Resolution Image of Spot 7 scale 1: 50,000 in 2018	Geospatial Information Agency	To create transect route guidelines
2	RBI map of the Ende Regency area scale 1 : 25,000	Geospatial Information Agency	As a base map
3	Spatial Detailed Plan Map for Ende City for 2017	Bappeda Ende Regency	To create a land use map
4	Landsat Image 8 of 2021	National Innovation Research Agency	To create land use map
5	Digital Elevation Model (DEM)	Geospatial Information Agency (BIG)	To create topographic and slope map
6	Map of the distribution of earthquakes in 2016-2022 in the waters of the southern part of the city of Ende	USGS	To distance the coast from the epicenter

Types of research

The type of research is quantitative research. The method used to analyse the level of tsunami susceptibility is through survey and spatial analysis. The survey was conducted in coastal areas to observe types of coastal typology and parameters used in analysing disaster susceptibility levels. Spatial analysis is undertaken through scoring and weighting to produce a tsunami susceptibility level. The purposive sampling method is used to determine sampling points. The sampling points were chosen based on the distribution of typologies and areas with the potential for tsunami disasters on the coast of Ende City.

Data Collection and Analysis

Primary and secondary data collection activities carry out the data collection process—primary data collection activities through field surveys. The survey was carried out to determine the physical condition of the land and coastal typology, as well as parameters that influence the level of tsunami susceptibility. The survey was also carried out to observe land use in the coastal areas of Ende City. Identification of coastal typologies in the field is guided by SPOT 7 Multispectral Satellite Imagery 2018 scale of 1:50,000. Validation of typology types in the coastal areas of Ende City was carried out by comparing the images on SPOT 7 Multispectral Satellite Imagery 2018 with the results of field observation. Secondary data collection activities through institutional surveys to obtain spatial and non-spatial data and literature studies to determine coastal typology.

Data analysis was carried out to determine coastal typology and level of tsunami susceptibility. Determining the coastal typology of Ende City was done by comparing the results of surveys and literature studies originating from the division of coastal typologies (Shepard, 1972; Pethic, 1984). Spatial analysis to determine the level of tsunami susceptibility in the coastal area of Ende City using Arc GIS software.

Geospatial parameters that influence the level of tsunami susceptibility in the coastal areas of Ende City are elevation, slope/slope of the coast, distance from the coastline, distance from the river, and distance from the epicentre and beach morphology. The parameters of elevation, slope, distance from the coastline and distance from the river are adjusted to the coastal characteristics of Ende City and by literature studies (Waskita, et al., 2020; Alwi & Mutaqin, 2022). The thematic map is obtained by extracting and classifying all parameters that influence tsunamis, then overlaying them and producing a map of the level of vulnerability to tsunami disasters on the coast of Ende City.

DEM (Digital Elevation Model) data processing obtained land height and coastal slope maps. These two maps were created by dividing the height and slope of the coast using value grouping (reclassify). The classification of elevation and slope is divided into five classes modified from (Faiqoh et al., 2013; Aslam et al., 2020). Distance from the coastline data uses an RBI map for the Ende Regency area at a scale of 1: 25,000. The distance from the coastline map is created by performing multiple ring buffers and grouping the values (reclassify). The classification of distances from the coastline is modified (Bretschneider & Wybro, 1976). River and settlement data were obtained from the RBI Map of the Ende Regency area at a scale of 1: 25,000. The distance map from the river is obtained by performing multiple ring buffers and reclassifying values. Distance from rivers information uses a modified classification from (Sinambela, 2014; Dewi, 2020). Distance from the epicentre of the earthquake data was obtained from data on the distribution of earthquake centres in the East Nusa Tenggara Province region in 2022 sourced from the U.S. Geological Survey Releases (USGS) 2022.

Determining tsunami susceptibility areas is done using the overlay method and data modelling. The tsunami vulnerability level map to choose an area at risk of a tsunami disaster is carried out using the Weighted Overlay method. The Weighted Overlay method is analysed spatially through overlay, scoring, and weighting techniques. The weighting and scoring process determines the differences in tsunami vulnerability levels for each parameter (Sinaga, et al., 2011; Subardjo & Ario, 2016; Suprihardjo & Candra, 2013). The weights and scores on all parameters are processed using Arc GIS software and produce a tsunami-prone area classification based on the tsunami disaster susceptibility level.

The weight assigned to each parameter ranges from 10-30%. Both large and small weights provide large and small contributions for each parameter in determining the level of tsunami susceptibility (Akbar et al., 2020). The weight given to each parameter determines the highest and lowest total scores.

The range of scores for each susceptibility class is obtained from the total of the highest scores minus the total of the lowest scores, divided by the number of susceptibility classes. The formula for obtaining a range of scores can be seen in Equation 1.

$$Sr=\sum(Bi \times Si\ Max) - \sum (Bi \times Si\ Min)\ldots\ldots\ldots(1)$$

Where :
Sr = Score Range
Bi = Weight for each criterion
Si = Score on each criterion
N = Susceptibility class (Subardjo & Ario, 2016)

The classification of the level of susceptibility to the tsunami disaster was produced into five classes, namely class with very susceptibility area, class with susceptibility area, class with slightly susceptibility area, class with safe area and class with very safe area from tsunami (Subardjo & Ario, 2016). The risks caused by tsunamis to coastal land use need to be assessed. Land use in the Ende City coastal areas exposed to the tsunami can be determined by making a land use map and overlaying it with a tsunami susceptibility map.

RESULTS AND DISCUSSION

Typology of Ende City Coastal Areas.

The coastal typologies found in the coastal areas of Ende City are the marine deposition coast typology (deposition of marine sedimentary material), the anthropogenic coast typology (artificial coastal typology), the wave erosion coast typology (wave activity typology), the sub-area deposition coast typology (accumulation of river sediment deposits) and volcanic coast typology (coastal typology due to volcanic processes).

Most of the typologies of Ende City's coastal areas are volcanic coast, followed by marine deposition coast typologies. Coastal areas consist of a combination of one or two coastal typologies. The presence of sand beaches characterises the marine deposition coast typology. The sand beach is composed of loose material, such as sand deposited on the beach by sea wave activity (Sunarto et al., 2014). The sand beach deposited in the bay area is called a pocket beach. The material that makes up the beach is black sand. Along the marine deposition coast typology are the Waru tree (Hibiscus tiliaceus), Beach Pandanus (Pandanus tectorius), and other terrestrial vegetation. Settlements are densely packed towards the mainland. The typology of marine deposition coast on the Arubara coast, Tetandara sub-district, contains constituent materials consisting of sand associated with volcanic breccia rock and coral reef fragments. In marine deposition coast typology in the Tanjung coastal area, the constituent materials consist of sand associated with volcanic breccia. The presence of culinary tourism buildings, bridges, abrasion prevention walls, breakwaters, seaports and fish harbours characterises the anthropogenic coast typology in the coastal area of Ende City. The potential for natural and culinary tourism is promising on the Ende coast.

Beach building materials typology wave erosion coast in the coastal area of Ende City is rock on steep hill cliffs resulting from wave erosion. The appearance of the wave erosion coast typology (wave activity) is characterised by seawater erosion that forms separate stacks or islands (Marfai et al., 2013). The stacks in the Mbu'u coastal area and the northern part of the Arubara coast originate from the collapse of coastal wall rocks. The characteristics of the wave erosion coast typology can be seen in the beach's winding, steep and irregular shape. The materials that makeup beaches are sand and large stones.

The volcanic coast typology is a coastal area located around the foot of the Iya volcano and the foot of the mountains. In this typology, volcanic breccia rocks form gravel cobbles and andesite rocks. The materials that make up the typology of sub-area deposition coast in the coastal area of Ende City consist of marine sand, gravel and river sedimentary sand. The Wolowona River causes the accumulation of river sediment materials, which is located on Mbu'u Beach. The coastal typology that forms the coastal area of Ende City can be seen in Figure 3.

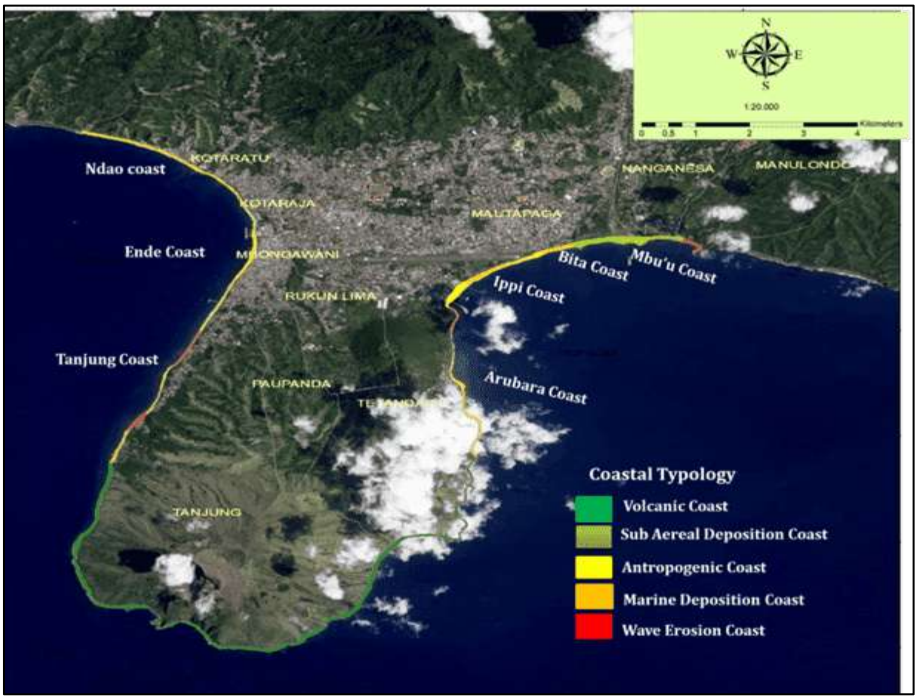

Figure 3: Typology Map of the Ende City Coastal Area
(Source: Analysis of Research Results, 2022)

Tsunami Disaster Susceptibility Analysis Based on Coastal Typology.
Elevation Classification.

The tsunami susceptibility elevation class is based on the tsunami run-up height classification (Lida, 1963). The distance or propagation of a tsunami is influenced by the strength of the tsunami energy, topography and differences in coastal typology. Areas with low elevations will be more susceptible to tsunamis. Elevation describes the difference in vertical distance between points and sea level. Elevation determines the level of susceptibility to tsunamis Field (Sinaga et al., 2011; Aslam et al., 2020); the higher the level of susceptibility, the higher the risk of a tsunami; conversely, the lower the topography of an area, the more often an area is submerged by tsunami runoff. The level of tsunami susceptibility based on elevation parameters in the coastal area of Ende City is shown in Table 3.

Table 3. Matrix and Results of Susceptibility Classification based on Elevation Parameters.

No	Distance(m)	Susceptibility	Area (m^2)	Percentage (%)
1	0- 50	Very Susceptibility	7.806,25	27,03
2	51-100	Susceptibility	5.025.85	17,40
3	101-200	Rather Susceptibility	6.681.76	23,13
4	201-500	Safe	8.315,36	28,79
5	501-1500	Very safe	1.054,17	93,65
		Amount	28.883,42	

(Source: Research Results, 2022).

The elevation of each coastal typology will influence the tsunami inundation area. The propagation of tsunami waves will easily reach areas with lower heights and can result in casualties and damage to settlements and other infrastructure. The extent of susceptibility classes varies for each coastal typology. This shows that coastal typology influences the extent of tsunami susceptibility from the coastline towards the mainland. Coastal areas with marine deposition coast, anthropogenic coast and sub-areal deposition coast typologies have the widest distribution of very susceptibility and susceptibility classes compared to the coastal areas with volcanic coast and wave erosion coast typologies. The distribution of areas with very susceptibility and susceptibility classes reaches almost half of the Ende City area. The topography of coastal areas is less than 50 meters. Coastal areas with high susceptibility are the Ndao coast of the City Ratu sub-district, the Ende coast of Kota Raja, Mbongawani, Rukun Lima, Paupanda sub-district, which is formed from the marine deposition coast typology, the Arubara coast and Ippi coast of Tetandara sub-district and the Bita Beach coast of Mautapaga sub-district which is formed from marine deposition coast and anthropogenic coast typology and the Mbu'u coast of Nanganesa village which is formed from the subaerial deposition coast typology. When a tsunami occurs in this typology area, it produces low wave heights. Tsunami propagation runs typically to reach land without any inundation. Tsunami wave propagation speed, sweeping the entire region towards the mainland. The Ndao coast area with the marine deposition coast typology is very susceptible to tsunamis, as seen in Figure 4.

The existence of an artificial typology (anthropogenic coast) causes the risk and danger of tsunamis to be higher because of dense settlements and tourism and transportation infrastructure. The level of exposure to the population and infrastructure influences the threat of a tsunami. Study (Jamila et al., 2021) in the coastal region of Pacitan, Indonesia shows a population with high community activity, dense settlement and infrastructure development. Causes a higher tsunami hazard with a broader coverage than the surrounding area.

The tsunami will usually spread

quickly in areas with a height of less than 100 meters, and the tsunami propagation will reach land areas of more than 500 meters towards Ende City. The level of tsunami vulnerability in the Tanjung coastal area with the marine deposition coast typology is lower than in the Ende coastal area with the same type of coastal typology. This is because the Tanjung coast is directly adjacent to cliffs and hills. This condition causes the propagation (run-up) of the tsunami towards land to be blocked by cliffs.

Figure 4. The appearance of the Ndao Coast with Marine Deposition Coast Typology
(Source: Researcher Documentation, 2021)

Figure 5. Appearance of the Volcanic Coast typology
(Source: Researcher Documentation, 2021)

The upper area of the mountain cliffs is safe from tsunamis. The risk level for tsunamis in the volcanic coast typology area is shallow because the land use consists of empty land, bushes and trees. A map of tsunami vulnerability levels based on land height can be seen in Figure 6.

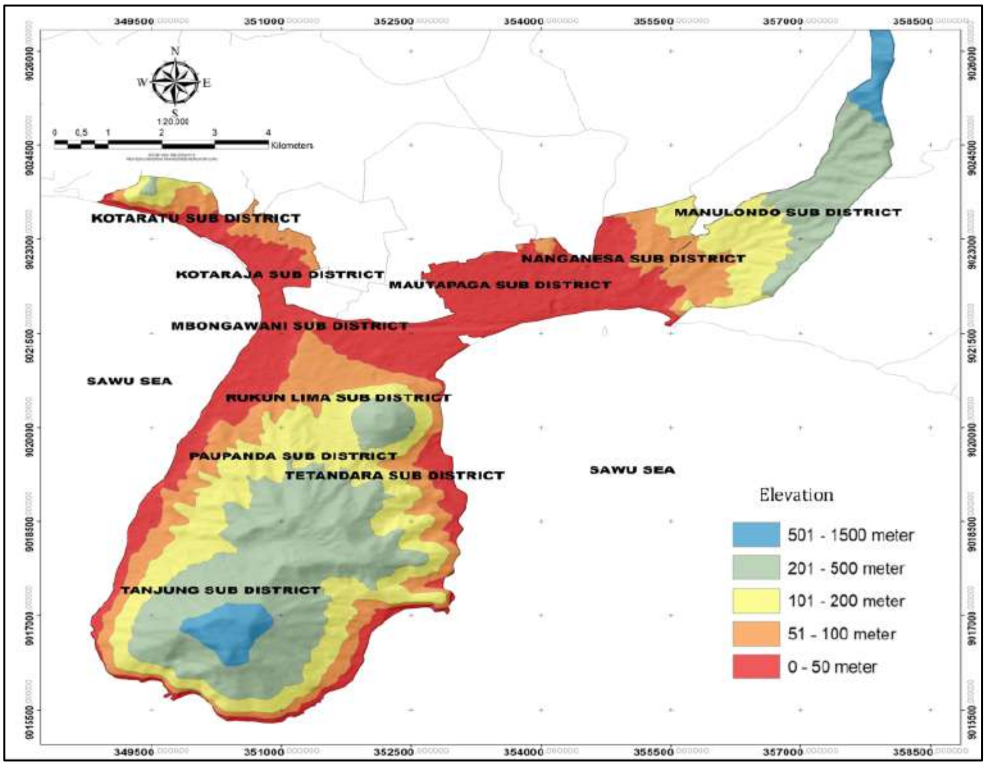

Figure 6. Map of Elevation in the Coastal Area of Ende City
(Source: Analysis of Research Results, 2022)

Slope Classification

The height of tsunami waves is lower on sloping and flat surfaces. Run-up tsunami waves will more easily enter land thousands of meters away with low or relatively flat slopes. At the same time, steep beaches will withstand and reflect tsunami waves (Safira et al., 2022; Aslam et al., 2020). The coastal areas of Ende City that are very susceptible are flat to gentle slopes with a slope of 0-6%. The area very susceptible to tsunamis is 2,385,618 km²; the slope percentage level is 8.37%.

Coastal areas that are very susceptibility to tsunamis are the Ndao coast of the City Ratu sub-district, Ende coast of Kota Raja, Mbongawani, Paupanda, Rukun Lima sub-district, part of the Tanjung coast of Tanjung sub-district, Arubara coast of Tetandara sub-district, Ippi coast of Tetandara sub-district, Bita Beach coast of Mautapaga sub-district, which formed from the coastal typology of marine deposition coast and anthropogenic coast, Mbu'u coast of Nanganesa village, which is formed from the sub areal deposition coast typology. The slope classification in the coastal area of Ende City consists of six slope classes and levels of susceptibility. Classification of susceptibility based on slope parameters can be seen in Table 4.

Table 4. Matrix and Results of Susceptibility Classification based on Slope Parameters.

No	Slope Type	Susceptibility	Wide (m²)	Percentage (%)
1	0-2 (Flat)	Very Susceptibility	312,66	1,10
2	3-6 (Sloping)	Susceptibility	2072,95	7,27
3	7-13 (Slightly Tilted)	Rather Susceptibility	4178,41	15,71
4	14-20 (Crooked)	Rather Safe	3858,02	13,53
5	21-55 (Steep)	Safe	14100,91	49,45
6	>55 (Very Steep)	Very Safe	3690,83	12,94
	Amount		28513,78	100

(Source: Research Results, 2022)

The risk caused by tsunamis is high in areas that are very susceptible to tsunamis due to dense settlements and other infrastructure in the coastal areas. There is a high risk in the marine, anthropogenic, and subareal deposition coast typology. The safe and very safe coastal area has coastal slopes of 21% -> 55% with steep to very steep slopes. The coastal area that is safe and very safe against tsunamis is 17,791,737 km^2 (62.39%). According to (Van Zuidam, 1985), mountain and volcanic landforms have a slope of >55% and above 1500 meters above sea level, and low hill landforms have a slope of >20% and a height of 100-200 meters above sea level. The high and steep landform does not cause tsunami inundation and propagation of tsunami energy, so coastal areas with the coastal typology of volcanic coast and wave erosion coast are safe from tsunamis.

The coastal areas that fall into the safe and very safe category against tsunami are the Tanjung coast of Tanjung sub-district with the volcanic coast typology, the northern Arubara coast of Tetandara sub-district and the Mbu, the coast of Manulando village with the wave erosion coast typology. The northern Arubara coastal area with the wave erosion coast coastal typology, which is included in the safe area against tsunamis, can be seen in Figure 7.

Figure 7.Wave Erosion Coast Typology with Stack on the Coast of Arubara
(Source: Researcher Documentation, 2021)

Steep coastal slopes prevent tsunamis from entering land because coastal cliffs block and reflect them into the sea. This coastal area is safe from tsunami run-up and tsunami inundation. The risk of a tsunami is low because, in this coastal area, there are no settlements or other infrastructure. The coastal land slope map is shown in Figure 8.

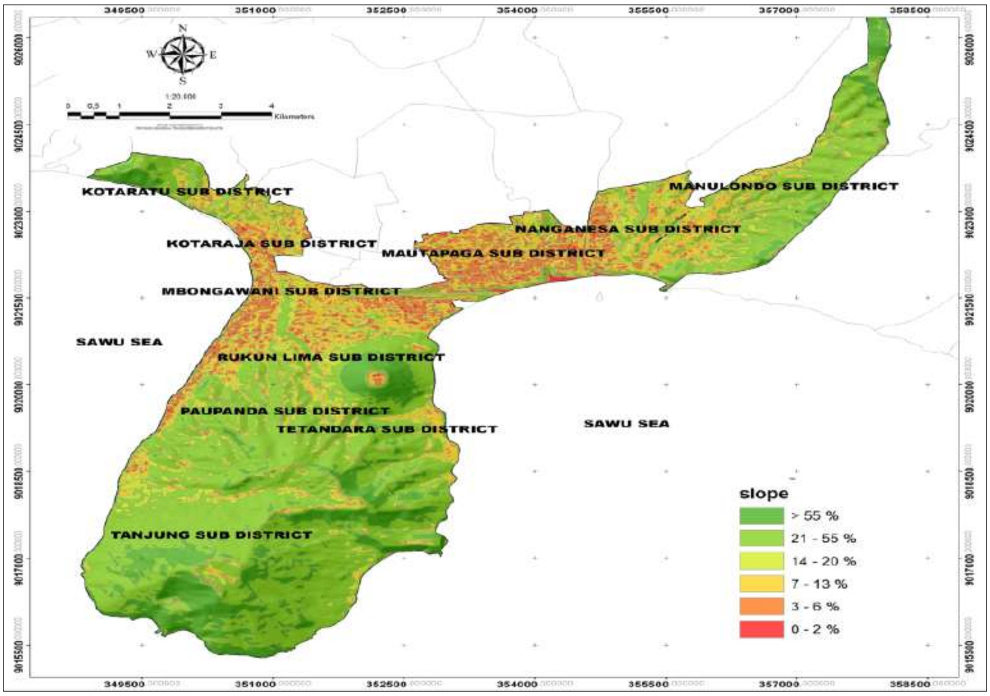

Figure 8: Slope Map of Ende City Coastal Area
(Source: Analysis of Research Results, 2022)

Classification of Distances from Shorelines.

Distance analysis from the coastline is carried out to determine safe areas from tsunamis. The distance from the coastline island along the coast, according to the shape and physical condition of the beach, is a minimum of 100 meters from the highest tide towards the mainland (Faiqoh et al., 2013). Areas close to the coastline have a high risk of tsunamis. Infrastructure with a dense population and very close to the coastline causes damage and loss when a tsunami occurs (Nucifera et al., 2019). The distance of settlements and infrastructure from the coastline is measured from the wave-breaking zone (breakers zone) (Bretschneider & Wybro, 1976). The smaller the distance between settlements and infrastructure from the breakers zone, the higher the level of tsunami susceptibility.

Coastal areas with the coastal typology of marine deposition coast, anthropogenic coast, wave erosion coast and subaerial deposition coast are most susceptible to tsunami waves. The distance of settlements and infrastructure from the coastline in the marine deposition coast, anthropogenic coast, and wave erosion coast typology is 0-50 meters. The distance from the coastline can be seen in Table 5.

Table 5. Matrix and Results of Classification Susceptibility Based on Distance from the Coastline

No	Distance (m)	Susceptibility	Area (m^2)	Percentage (%)
1	0 – 50	Very Susceptibility	982.861	3,40
2	51 – 100	Susceptibility	1.093.843	3,79
3	101 -150	Rather Susceptibility	1.084.864	3,75
4	151 – 200	Rather Safe	1.075.496	3,72
5	201 – 250	Safe	1.062.347	3,68
6.	>250	Very Safe	23.599.803	81,66
	Total		28.899.214	100

(Source: Analysis of Research Results, 2022)

Coastal areas with the typology of marine deposition coast, anthropogenic coast and sub-aerial deposition coast are the most susceptible areas and have a very high-risk level for tsunami propagation. The appearance of the anthropogenic coast typology in the Ende coastal area, which is very susceptible to tsunamis, can be seen in Figure 9.

Figure 9. Ende Coast Appearance with Anthropogenic Coast Typology
(Source: Researcher Documentation, 2022)

Administrative areas that are included in areas that are very susceptibility to tsunamis and have a high risk of tsunami are the sub-districts of the City Raja, the City Ratu, Mbongawani, Rukun Lima, Paupanda, Tanjung, Tetandara, Mautapaga and Nanganesa Village. A map of the distance from the coastline can be seen in Figure 10.

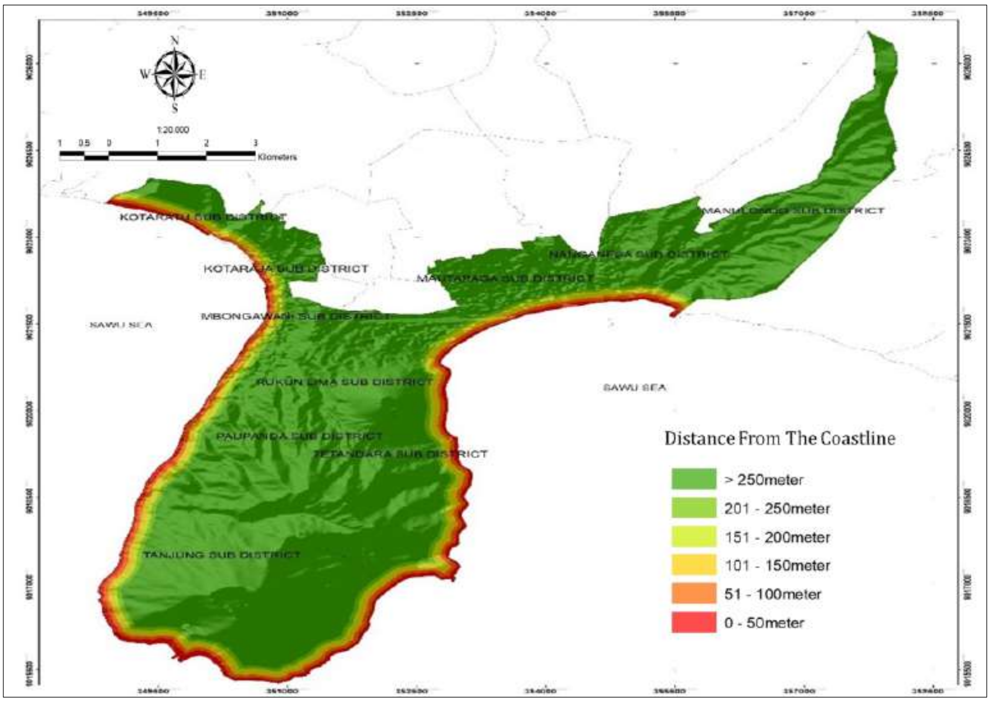

Figure 10. Map of Distance from Coastline (Source: Analysis of Research Results, 2022)

Classification of Distances from Rivers.

The closer the settlement is to the river, the higher the danger and risk of a tsunami. Sea water can rise freely through river flows without being obstructed by anything. According to (Laksono et al., 2022), tsunamis quickly enter river bodies and cause the area around the river to be inundated with water because the river cannot accommodate the volume of water. The farther an area is from a river, the safer the area is from the impact of a tsunami.

Settlements on the east coast and around the Wolowona River basin are close to the river. The distance of settlements and infrastructure from the river is less than 150 meters. This distance is the closest distance class and is very susceptible to tsunamis. The class distance from the river of less than 150 meters occupies an area of 449,073 m² and a percentage of 1.55%. A map of the distance from the river can be seen in Figure 11.

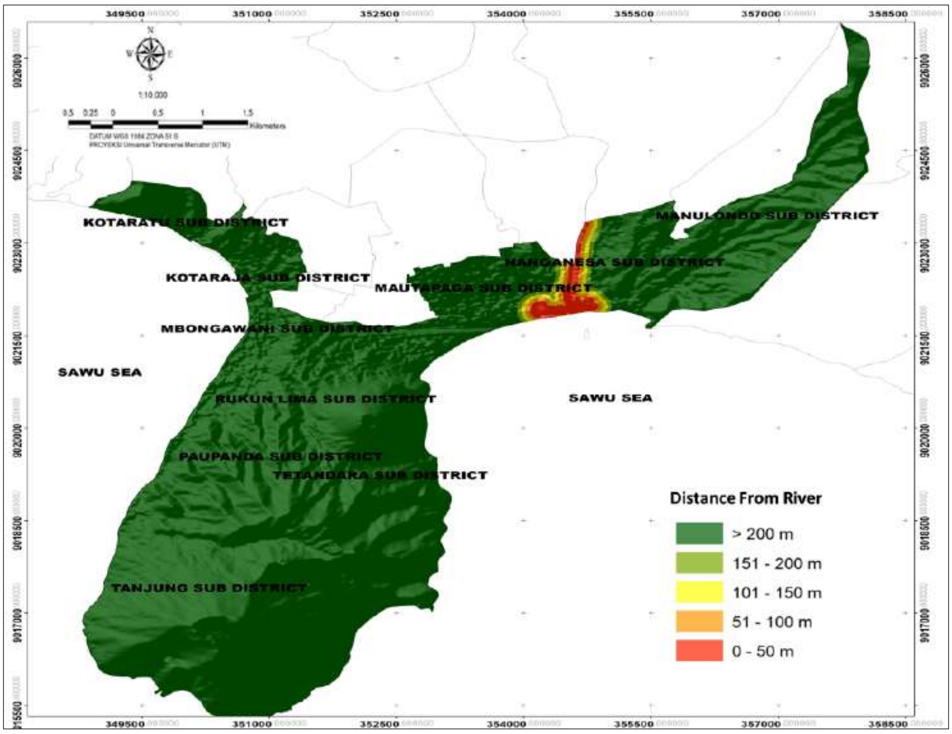

Figure 11. Map of distance from the river (Source: Analysis of Research Results, 2022)

The coastal typology in the river estuary area is a sub-aerial deposition coast typology. The sub-aerial deposition coast typology with a relatively straight and sloping coastline is most vulnerable to tsunami propagation. The results of the study confirm this (Yuniastuti, 2016) subareal deposition coast typology in the Demak coastal area is an area formed by an accumulation of river sediment material with a gentle slope of <20%, with mud and sand as the beach material. Specific characteristics of the sub-aerial deposition coast typology are very susceptible to tsunamis. Rivers are one of the landforms that are susceptible to tsunamis. The tsunami will enter further inland through the river basin. The tsunami propagation will move quickly to land because the river body is a tsunami propagation medium (BNPB, 2018).

The sub-aerial deposition coast typology is included in the administrative area of the Mautapaga sub-district and Nanganesa village. Land uses in this area are residential areas, swamps, lakes, chicken farms, plantations, agriculture, lake tourism and hotels. If a tsunami occurs, it will destroy settlements and other infrastructure around the river mouth. The classification of tsunami susceptibility levels based on the distance from the river parameter can be seen in Table 6.

Table 6. Matrix and Classification Results for Distance from the River

No	Distance(m)	Susceptibility	Area (m²)	Percentage (%)
1	0-50	Very Susceptibility	284,32	97,38
2	5 -100	Susceptibility	164,75	0,98
3	100 -150	Rather Susceptibility	156,40	0,57
4	151- 200	Safe	151,4	0,54
5	> 200	Very Safe	28.141,09	0,53

(Source: Analysis of Research Results, 2022)

Classification of Coastal Distance from Earthquake Center.

A classification of the distance from the coast to the source that caused the tsunami was carried out to find out the research area affected by the tsunami. The closest distribution of earthquake centres that affected Ende City and its waters was the distribution of earthquake centres in the southern waters of the island of Flores. The distance of the coast from the epicentre can be seen in Figure 12.

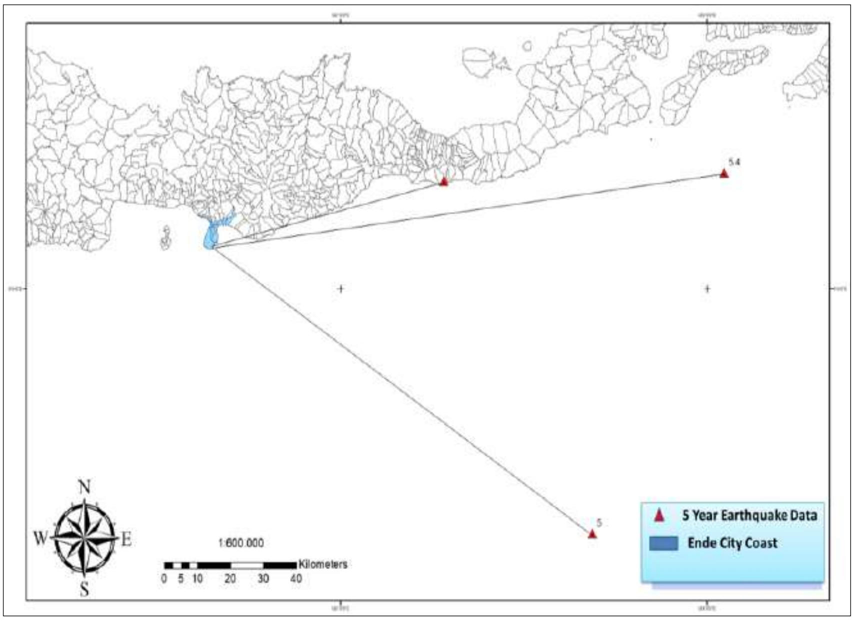

Figure 12. Map of Coastal Distance from Earthquake Center (Source: USGS, 2022)

Coastline Morphological Classification.

The coastline's shape or morphology determines the tsunami susceptibility level on the coast of Ende City. The coastal bays in the coastal area of Ende City are the western and eastern coasts of Ende City. The coastline has a bay (concave shape) with a high susceptibility to tsunamis. According to this (Ikawati, 2004), areas located perpendicular to the direction of the tsunami waves are affected by the energy concentration in the bay.

Coasts in the form of bays are susceptible to tsunamis because they are related to the wave energy concentration, which increases the speed of wave propagation and water level. The event of water movement in a medium, the smaller the area of the water medium through which the sea level rises and the speed of propagation increases. Tsunami waves entering the Bay Area will result in more significant energy accumulation, increasing the danger level (Jamila et al., 2021).

The height and speed of tsunami propagation on the western coast differs from the eastern coast of Ende City. Differences in tsunami wave height are due to differences in coastal morphology and typology. Classification of tsunami susceptibility based on coastline morphological parameters is shown in Table 7.

Table 7. Matrices and Coastline Morphology Classification Results.

No	Coastline Morphology	Susceptibility	Typology	Coast
1	Concave Beach (Bay Beach)	Susceptibility	Marine deposition coast, antropogenic coast, wave erosion coast, sub aereal deposition coast.	Ndao, Ende, Tanjung, Ippi,Bita Beach, Mbu'u
2	Convex Beach (Cape Beach)	Very Susceptibility	Volcanic coast, wave erosion coast	Tanjung bagian selatan Arubara bagian selatan
3	Straight Beach	Rather Susceptibility	Marine deposition coast, antropogenic coast	Arubara

(Source: Research Results, 2022)

Ndao coast, Ende coast (western coast of Ende City), Ippi coast, Bita Beach coast, and Mbu'u coast (eastern coast of Ende City) are bay-shaped coasts. They are formed from marine deposition coast, anthropogenic coast and sub-aerial deposition coast typologies. Mountains and hills border this coastal area on the right and left sides. These coastal morphological conditions cause a concentration of tsunami energy. The concentration of tsunami energy causes an increase in tsunami height, and the tsunami propagates freely towards land. A tsunami that hits the coastal typologies of marine deposition coast, anthropogenic coast and sub-aerial deposition coast in the bay area will propagate further inland more quickly because the thrust of the tsunami energy is more potent in a narrow area.

On the coast of Arubara, the Tetandara sub-district, which is formed from the typology of marine deposition coast and anthropogenic coast, has straight beach morphology; this causes tsunami waves to spread along the coast so that the tsunami landfall does not go far inland. Areas with convex coastal morphology are the southern Tanjung coast, the Tanjung sub-district and the Mbu'u coast of Manulando village. The south of Tanjung coastal area is formed from the volcanic coast typology, and the Mbu'u coast is formed from the wave erosion coast typology. The coastal landform of southern Tanjung is a coastline bordered by mountains, and hills border the coastal landform of Mbu'u.

This area is very susceptible to tsunamis because the convex morphology of the coast causes the propagation, height and speed of tsunami waves to easily and very quickly reach the area freely without obstacles. The coast morphology in the coastal area of Ende City is shown in Figure 13.

Determination of Tsunami Susceptibility Areas.

Based on Figure 14, from the results of GIS analysis and modelling, the level of susceptibility to tsunami disasters in the coastal areas of Ende City is divided into five classes. The five classes are very susceptibility, susceptibility, rather susceptibility, safe and very safe. The area that is very susceptible to tsunamis has an area of 125.3 m² or 0.43% of the total area of Ende City. Areas susceptible to tsunamis have an area of 28,253.66 m² or 9.77% of the total area of Ende City. The area somewhat susceptible to tsunamis has an area of 85,290 m² or 29.56% of the total area of Ende City. Areas that fall into the categories of very susceptibility, susceptibility and rather susceptibility are areas formed from the coastal typology of marine deposition coast, anthropogenic coast and sub-area deposition coast. This area has a flat to gentle coastal slope; the coastal material consists of sand, the land height reaches less than 200 meters, the distance from the river is less than 150 meters, the beach morphology is convex and forms a bay, there are no coastal protection buildings, and the coastal vegetation is sparse.

The tsunami-safe area has an area of 145,421.28 m² or 50.26%. The area included in the very safe category has an area of 28,883.68 m² or 9.98% of the total area of Ende City. Areas that are safe and very safe from tsunamis are formed from wave erosion coast typology and volcanic coast typology. Safe and very safe areas are areas above 200 meters with steep slopes. A map of the level of tsunami vulnerability in the coastal areas of Ende City can be seen in Figure 14.

Figure 13. Coastal morphology of The Western Part and The Eastern Part of Ende City
(Source: Researcher Document, 2022)

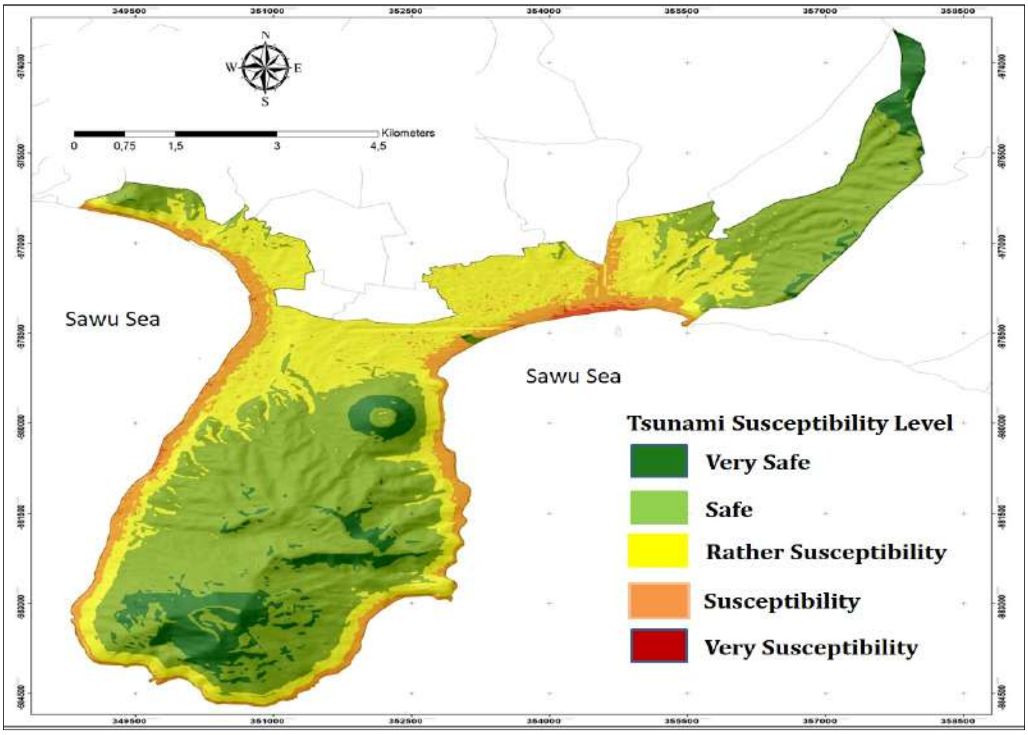

Figure 14. Map of Tsunami Susceptibility Level in the Coastal Area of Ende City
(Source: Analysis of Research Results, 2022)

Based on the analysis results, the most significant area is the area that is safe from tsunamis. This region is a highland area, namely mountains and hills. Areas susceptible to tsunamis are coastal areas extending towards land or cities. The classification of tsunami susceptibility levels can be seen in Table 8.

Table 8. Classification of Tsunami Susceptibility Levels.

No	Tsunami Susceptibility	Area (m2)	Prosentage (%)
1	Very Safe	2.889.0	9,98
2	Safe	14.545.7	50,26
3	Rather Susceptibility	8.554.5	29,56
4	Susceptibility	2.826.3	9,77
5	Very Susceptibility	125.3	0,43
	Total	28.940.9	100

(Source: Research Results, 2022)

Tsunami Susceptibility and Land Use Classification.

Land use in tsunami susceptibility areas is known by overlaying tsunami susceptibility maps and land use maps. Most of the population and valuable infrastructure in the coastal regions of Ende City occupy very susceptibility, susceptibility and rather susceptibility coastal areas. Land use in the coastal area of Ende City consists of residential areas, religious facilities, educational facilities, forests, mixed gardens, military facilities, trade and service facilities, government offices, grass/empty land, bushes, cemeteries, road networks, the Gunung Meja area, Mount Iya area, transportation facilities, sandy beaches, public facilities, health facilities, sports facilities, socio-cultural facilities, rocky beaches, warehouses, rivers/waters, communication facilities.

The tsunami susceptibility to land use needs to be studied because tsunamis cause changes in land use. The impact of the tsunami on each land use is different. The tsunami that hit settlements caused enormous damage to settlements, property loss and loss of life (Faiqoh et al., 2013). Land use in the coastal area of Ende City is seen in Figure 15.

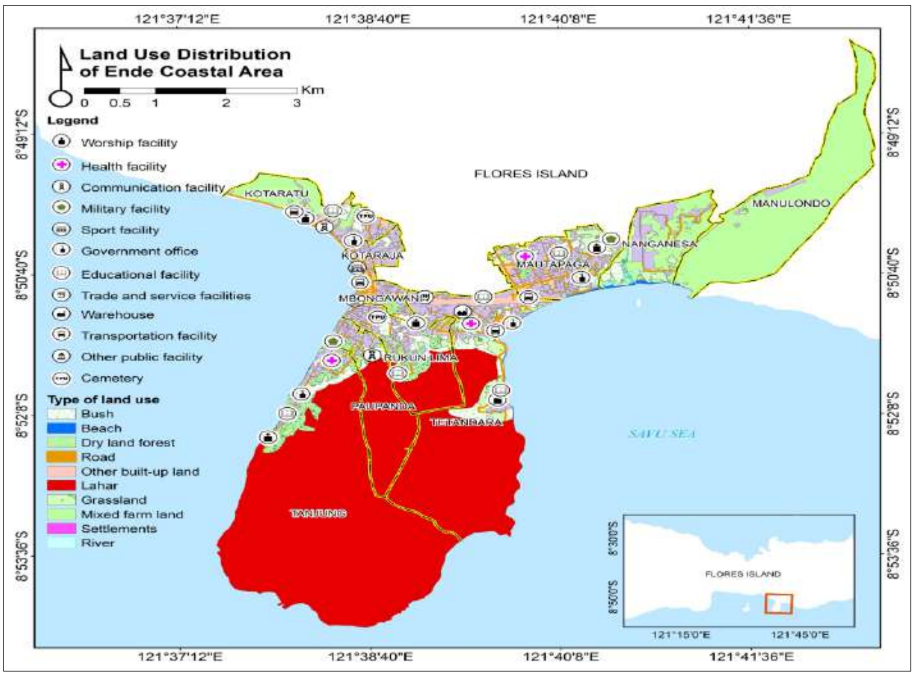

Figure 15. Land Use Map (Source: Analysis of Research Results, 2022)

Most residential areas, educational facilities, worship facilities, trade and service facilities, government offices, health facilities, road networks, transportation facilities, sports facilities, socio-cultural and communication facilities, military facilities, trade and service facilities, public facilities and communication facilities are located in locations susceptibility to tsunamis. This means that many people are at high risk of a tsunami disaster. There is a high risk that a tsunami will cause large amounts of damage and loss of life. The most significant land use is 14,801,207 m^2, included in the safe area are mountains and volcanoes.

Based on studies (Sinaga et al., 2011; Akbar et al., 2020; Amri & Giyarsih, 2022; Amri et al., 2023), in several coastal areas of Indonesia, although the area safe from the tsunami is the largest, most of the built-up land, such as settlements, infrastructure, public facilities and population, are in tsunami susceptibility zone. This indicates that many populations are at risk of tsunamis. Serious mitigation efforts are needed to prevent future disasters and significant loss of life.

CONCLUSION

The tsunami susceptibility level of the coastal areas of Ende City is influenced by coastal typology and tsunami susceptibility parameters. The geospatial parameters that produce tsunami susceptibility maps in the coastal regions of Ende City are elevation, slope, distance from the coastline, distance from the river, distance from the epicentre, land protection and coastline morphology.

The very susceptibility area has an area of 125.3 m^2, the susceptibility area has an area of 2828.3 m^2, the rather susceptibility area has an area of 8554.5 m^2, the safe area has an area of 14,545.7 m^2, the very safe area has an area of 2889 m^2. Very susceptibility, susceptibility, and rather susceptibility tsunamis are areas with the coastal typology of marine deposition coast, anthropogenic coast, and sub-area deposition coast. Areas that are safe against tsunamis are coastal typologies of wave erosion coast. The safest coastal areas are volcanic coast typology.

Based on the results of the overlay of land use maps and tsunami susceptibility maps, settlements, infrastructure such as religious facilities, educational facilities, military facilities, public facilities, services and trade, offices, roads, communication facilities, coastal forests, fresh waters are in areas susceptibility to damage tsunami and have a high risk of tsunami hazards. Future development in the Ende City area should avoid areas susceptible to tsunami hazards.

ACKNOWLEDGEMENTS

The authors would like to thank the Education Fund Management Institute (LPDP) Ministry of Finance of the Republic of Indonesia for financing this research, the Geospatial Information Agency (BIG), National Aeronautics and Space Agency (LAPAN), National Research and Innovation Agency of the Republic of Indonesia (BRIN), U.S. Geological Survey (USGS) for datasets, Geography Doctoral Study Program, Faculty of Geography, Gadjah Mada University and colleagues for assistance with fieldwork.

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