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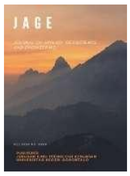

GIS-Based Natural Disaster Vulnerability Mapping in Donggala Regency, Central Sulawesi Province

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ABSTRACT

Donggala Regency has diverse morphology, encompassing coastal areas and complex hilly terrains. Geomorphological studies are essential for understanding landforms and assessing the potential for related natural disasters. This study aims to identify dominant landforms and assess natural disaster vulnerability, including landslides, tsunamis, and liquefaction, using a Geographic Information System (GIS)-based approach. The methods employed in this research include the analysis of topographic maps, satellite imagery, and a review of literature on geological conditions. The results indicate that coastal areas are highly vulnerable to tsunamis, while hilly regions are more susceptible to landslides.

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1. INTRODUCTION

Natural disasters are unforeseen phenomena that may result in substantial adverse effects on communities, including loss of life, physical destruction, and non-material damage (Faizana et al., 2015). Donggala Regency, located in Central Sulawesi, Indonesia, is characterized by a complex geomorphological landscape comprising coastal zones, river valleys, and mountainous regions. This geographical diversity makes the area highly susceptible to natural disasters such as tsunamis, landslides, and liquefaction, which have historically caused significant loss of life and infrastructure damage (BNPB, 2019).

Soil liquefaction represents one of the most destructive geotechnical phenomena triggered by seismic events. It is widely acknowledged that the failure of numerous engineering structures has been attributed to the loss of soil strength and stability caused by liquefaction during earthquakes (Habibullah et al., 2012). Central Sulawesi is a region with high seismic activity and earthquake frequency (Zeffitni et al., 2019). The urgency to understand and manage these hazards has increased, especially after the devastating 2018 Palu-Donggala earthquake and tsunami. Integrating geographical information systems (GIS) into disaster risk assessment has become a powerful approach for spatially analyzing and visualizing vulnerability zones (Dhakal et al., 2000). GIS technology serves as a versatile tool for problem-solving in multiple fields. In the agricultural sector, it aids in monitoring earthquake data and managing recovery processes. By employing spatial queries and weighted map-overlap analysis, GIS can predict potential disaster zones. For these systems to function effectively during a crisis, adequate physical infrastructure must be in place to support the data (Tambunan, 2025). This study aims to develop a GIS-based vulnerability map for Donggala Regency by combining spatial parameters such as land use, slope, soil type, and proximity to fault lines and coastlines. The analysis focuses on three main types of disasters:

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landslides, liquefaction, and tsunamis. The resulting maps are expected to be essential for regional planning, early warning systems, and community-based disaster risk reduction. By providing a scientifically grounded and spatially explicit vulnerability assessment, this research contributes to more targeted and effective disaster mitigation strategies in one of Indonesia's high-risk regions.

2. METHOD

This study adopts a spatial analysis approach using Geographic Information Systems (GIS) to assess natural disaster vulnerability in Donggala Regency. The methodology consists of several key stages: data collection, parameter selection, spatial data processing, weighted overlay analysis, and vulnerability mapping.

2.1 Study Area

Geographically, Donggala Regency is located between the coordinates of 0°13'-1°20' South latitude and 119°35'-120°15' East longitude. The study area includes various morphological units such as structural hills, alluvial plains, and coastlines directly facing the Sulawesi Sea. Sub-districts in the study area include Banawa, Central Banawa, Sindue, Sirenja, Balaesang, and Dampelas. Its geographical setting includes tectonic fault zones and sediment-prone coastal plains, making it highly vulnerable to earthquakes, tsunamis, and landslides.

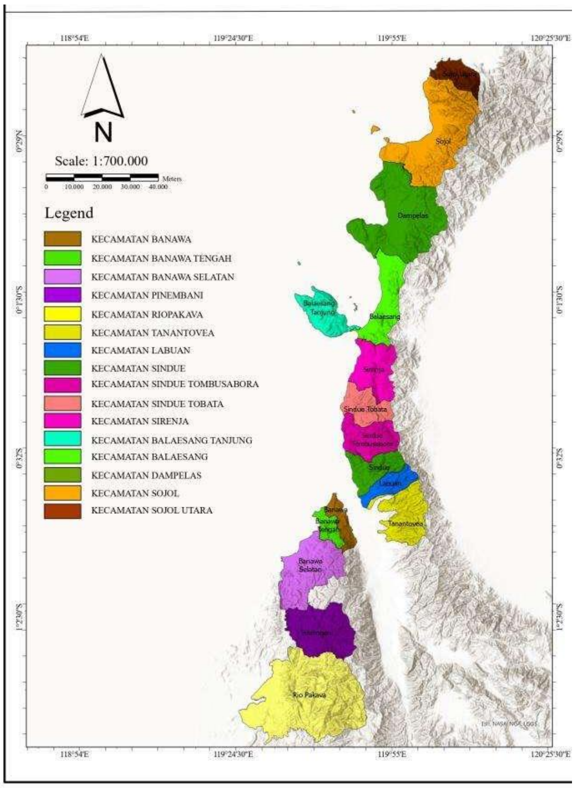

Figure 1. Map of the research location

Table 1. Total datasets/class

Class	Training Data	Test Data
Ring	95 Images	22 Images
Corrosion	58 Images	15 Images
Amount total	286 images	81 images

2.2. Data Collection

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Various spatial and non-spatial datasets were collected from primary and secondary sources:

- Topographic data: Shuttle Radar Topography Mission (SRTM) 30m resolution DEM for slope and elevation analysis.
- Land use/land cover (LULC): Acquired from Indonesian Geospatial Information Agency (BIG) and satellite imagery interpretation.
- Geological and soil maps: Obtained from the Geological Agency of Indonesia.
- Rainfall data: Acquired from BMKG (Indonesian Meteorological, Climatological, and Geophysical Agency).
- Historical disaster data: Sourced from BNPB (National Disaster Management Agency) and Inarisk portal.
- Administrative boundaries: Provided by BIG.

2.3. Parameter Selection and Classification

Parameters were selected based on relevance to each disaster type and literature review. Key parameters include:

- For landslide vulnerability: slope, lithology, land use, and rainfall intensity.
- For liquefaction: soil type, groundwater level, and historical seismicity.
- For tsunami: elevation, distance from the shoreline, land cover type, and coastal slope.

Each parameter was reclassified into vulnerability classes (e.g., very low to very high) and assigned a score from 1 (very low) to 5 (very high), based on technical guidelines from PVMBG (2004), RBI (2016), and other validated sources.

3. RESULTS AND DISCUSSION

3.1. Landslide

A landslide is a type of ground movement; generally, the ground movement that occurs is a debris avalanche. Gravity and seepage forces are the main causes of instability on natural slopes and slopes formed by excavation or filling. Landslides are an example of a geological process called mass wasting, which is often also called mass movement, which is the movement of masses of rock, regolith, and soil from a high place to a low place due to gravity (Dwiyanto, 2012). Geomorphologically, the hilly region of Donggala has steep slopes with varied rock types, including sedimentary and igneous rocks that are easily weathered. The combination of complex geological structures and high rainfall, especially during the rainy season, increases the potential for ground movement.

There are landslide hazard zoning map parameters

1) Slope

Slope is one of the factors that affect the occurrence of erosion and landslides. Therefore, it is necessary to know the slope percentage. To find the slope percentage, scoring based on PVMG slope classification (2004) is used. The slope factor is classified into 5 classes of percent slope, as seen in Table 1.

Table 1. Classification of Slope

Class	Criteria (slope weight)	Score
Slope	0-8%	1
steep	8-15%	2
slightly steep	15-25%	3
steep	25-45%	4
very steep	>45%	5

Source: PVMBG (2004)

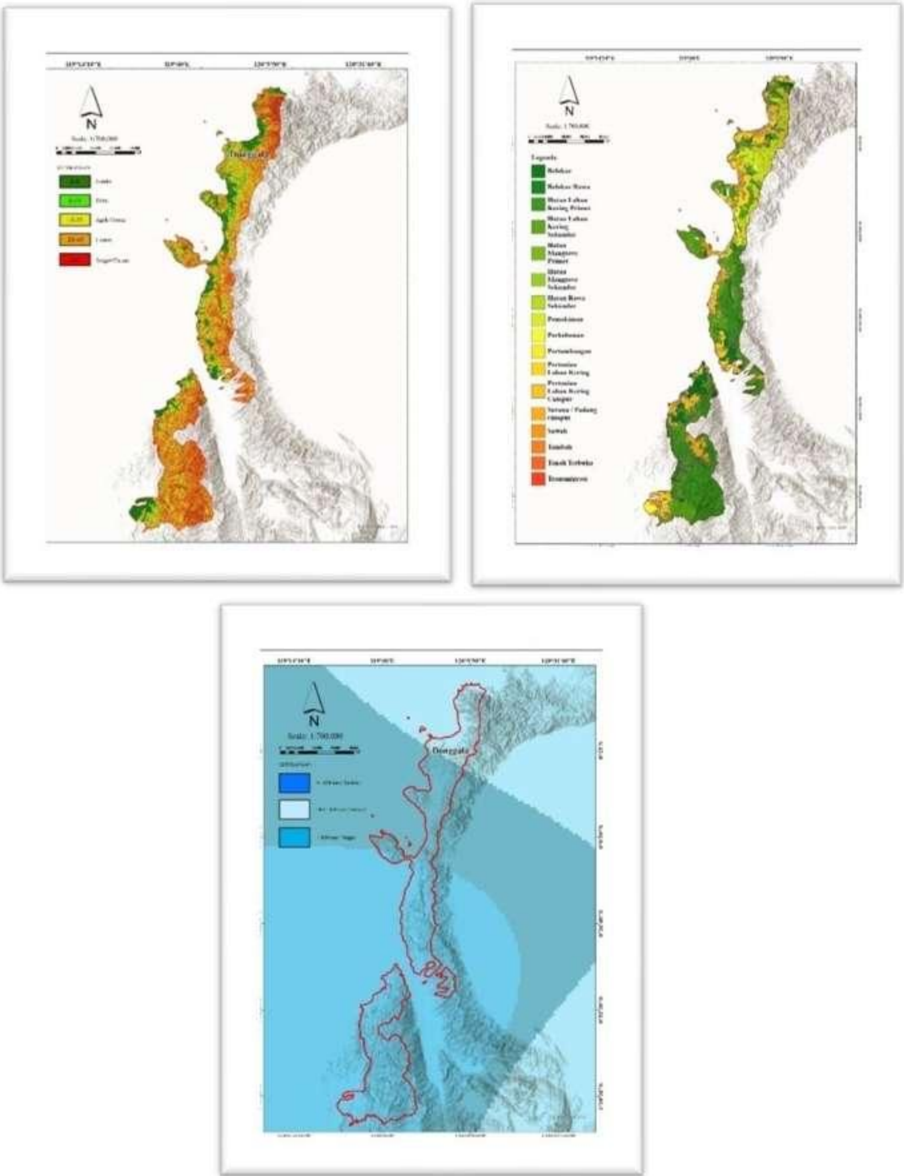

Figure 2. Slope Zoning, Land Use, and Rainfall Zoning Maps

1) Land Use

The land use parameter divides land types based on their function. Land use affects the soil load and the area's level of stability (Mardalena et al, 2023). In this research, land use interpretation is done by processing satellite imagery and land use data from related agencies, which is then classified into several categories of dominant land use in the area, as shown in Table 4.2.

Table 2. Land Use Classification

Parameter	**Classification**	**Score**
Land use	River	1
	Scrub/shrub, dense forest, sparse forest	2
	Mixed farms and plantations	3
	Farmland	4
	Rural settlement, rain-fed rice fields, irrigated rice fields, industry	5

2) Rainfall

Rainfall is one of the factors determining the level of potential landslide hazard in the study area. The higher the rainfall value, the more certain it is that the area is a landslide hazard area. In this

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study, the annual rainfall value was determined using secondary data from BMKG, 2025 and then processed using ArcGIS PRO software. Can be seen in Table 3.

Table 3. Rainfall Classification

Rainfall (mm)	classification	Score	weighting
2001-2500	Low	1	3
2501-3000	Medium	2	6
3001-3500	High	3	9
>3501	Very High	4	12

Source: BMKG 2013; Taufik & Firdaus (2012)

After the weighting step, the next step is to create a map according to the weighting/scoring using ArcGIS Pro software, where each screen parameter is processed in raster form. The overlay process is carried out with the weighted parameter overlay method to produce a map zoning map vulnerability disaster of landslides (Figure 3) based on the accumulated value score from each parameter that has been previously determined.

After the process using the existing formula, the value of the disaster vulnerability level is obtained. The level of vulnerability is divided into 3 levels of vulnerable zones as seen in the following table:

Table 4. Scorring Parameter

Level of vulnerability	Area km^2
Low	67,9046
Medium	13366,0449
High	2234,7649

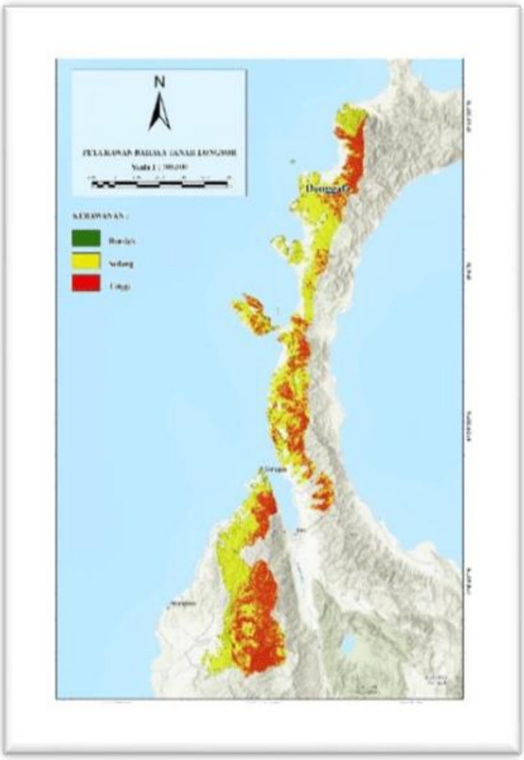

Figure 3. Lanslide-prone Map

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The result of overlaying spatial data of slope, rock type, and land use resulted in a map of landslide hazard zoning map which is divided into three categories: low, medium and high.

- Low landslide prone area with an area of 67,90 km^2 of the study area which is generally relatively gentle slope condition.
- Moderate landslide prone area, with an area of 1366,04 km^2 which generally has relatively steep slopes.
- High landslide prone area, with an area of 2234,76 km^2 of the study area which generally has steep-very steep slopes.

3.2 Liquefaction

There are liquefaction hazard zoning map parameters:

1) Soil Type

Soil type is a number of characteristics used to classify and distinguish one type of soil from another and its effect on erosion/landslide. Therefore, it is necessary to know the type of soil found in an area in order to assess slope stability more accurately. To be able to know the type of soil used, classification can be seen from the following table.

Table 5. Classification of Soil Types

Parameter	Classification	score
Soil type	Regosol	5
	Andosol, podzolic	4
	Brown latosol	3
	Yellowish brown latosol association	2
	Alluvial	1

2) Groundwater Table

The water table is the boundary between the saturated and unsaturated zones in the soil, where all soil pores below the boundary are completely filled with water. The water table is one of the factors in identifying liquefaction potential as it is closely related to the degree of soil saturation to air. The classification used in the groundwater table in determining liquefaction is as follows.

Table 6. Classification of Groundwater Table

Classification	Score
Very shallow	1
Not shallow	2
Shallow	3
Somewhat shallow	4
Very shallow	5

3) Historical Event Data

Historical event data is information that records earthquakes or ground shaking events that have occurred in an area. This data is very important for assessing the potential for liquefaction to occur, as earthquake events provide an overview of the response of the soil to a vibration. Therefore, the collection of historical event power is an important part of liquefaction risk evaluation and disaster mitigation planning in earthquake-prone areas.

Areas that have a high level of susceptibility to liquefaction are generally located in the lowlands near the coast and large rivers, such as around Banawa Sub-district and its surroundings. After identification through existing maps using data sourced from inarizk, the level of disaster vulnerability value is divided into 3 categories with different colors and can be explained in the following table

Table 7. Scorring Parameter

Level of vulnerability	Area km^2
Low	1.324
Medium	59,60021047
High	769,818549

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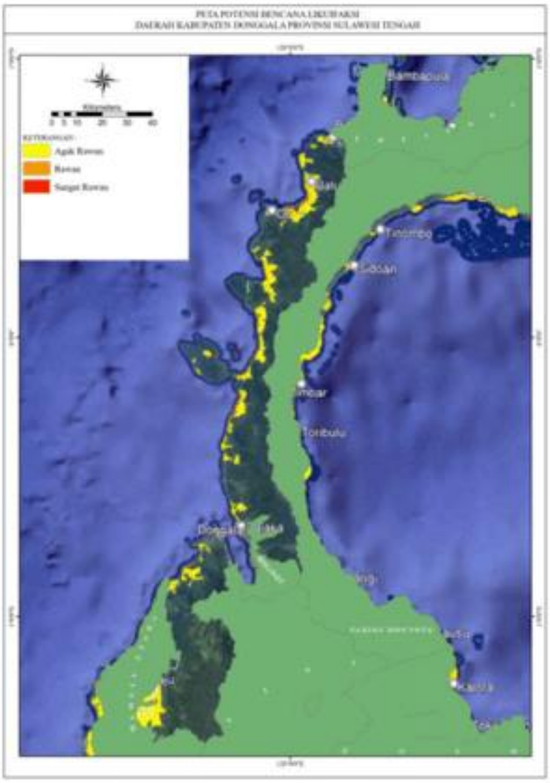

Figure 3. Liquefaction-prone Map

The results of overlaying spatial data on soil type, groundwater level, and event history in the map legend are divided into several categories marked with different colors, namely.

- Red zones indicate areas with the highest level of susceptibility to liquefaction.
- Orange zones indicate areas of moderate vulnerability. These areas have the potential to experience liquefaction, but the intensity and impact may not be as great as in the red zone.
- Yellow zones, areas with a low potential for liquefaction, but still need to be aware due to changes in geological conditions or the intensity of earthquake intensity may increase their vulnerability.

On the resulting map, Donggala has a high liquefaction potential due to various geological factors. Some areas in donggala that are considered high risk include Banawa, Banawa Selatan, Labuan and Tanantovea. These areas have a combination of water-saturated soils and high potential for earthquake shaking, so it is important that comprehensive disaster mitigation efforts are carried out.

3.3 Tsunami

There are tsunami hazard zoning map parameters:

1) Land elevation

Land elevation refers to the human use of land, including the various activities or functions applied to a particular area. This parameter is used to provide information on the vulnerability of an area to the impact of a tsunami. The classification used in land use is as follows.

Table 8. Clasification of Land elevation

Classification	Description	Score
Settlement, Forest Swamp, River, Rice Field	Very High	5

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Plantation / Land Vegetation	High	4
Field/Field	Medium	3
Scrub, Lake, Reeds	Low	2
Forest, rock, limestone, rocky area	Very Low	1

2) Soil Evaluation

Soil evaluation is an analysis of the physical and geotechnical conditions of the soil that can influence the impact of a tsunami on an area. One of the main parameters is soil type, where sandy soils are prone to erosion and shifting tsunami wave forces. This can be seen through the following classification:

Table 9. Classification of Soil Evaluation

Classification	**Description**	**Score**
0 - 20 m	Very High	5
21 -50 m	High	4
51 - 100 m	Medium	3
101 - 300 m	Low	2
> 300 m	Very Low	1

3) Slope

Slope is the angle or degree of inclination of a land surface or hill against a flat horizonta line which is usually expressed in the form (%). Slope This describes how steep or gentle a slope is and is one of the important factors in the field of geotechnics and natural disaster mitigation. Therefore, slope becomes an important parameter in mapping the risk of tsunami disaster and this parameter can also be seen using the following slope classification:

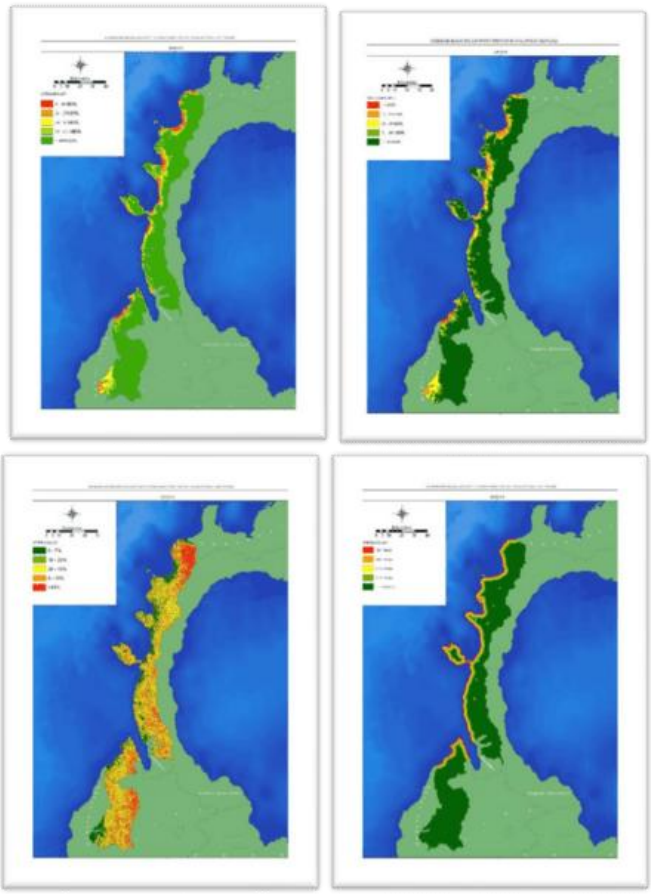

Figure 4. Land elevation, Soil elevation, Slope, and Coastal Distance Maps.

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Table 10. Slope Classification

Classification	**Score**
0 – 8 %	1
8 – 15 %	2
15 -25 %	3
25 – 45 %	4
> 45 %	5

4) Coastal distance

Coastal distance is an important aspect in assessing the vulnerability of an area to the impact of direct tsunami waves. Areas within a few hundred meters radius from the coast are generally considered to be very vulnerable, as they have very limited time to evacuate after a tsunami-triggering earthquake. Therefor the coastline is essential for tsunami-prone zones, the determination of evacuation routes and spatial planning. This can be seen through the following classification.

Table 11. Coastal distance classification

Distance	**Score**
0 – 500 m	5
>500 – 1000 m	4
>1000 – 1500 m	3
>1500 – 300 m	2
>3000 m	1

Tsunami hazard zonation is generated from the analysis of distance to shoreline and elevation data. Zones with high hazard levels are dominantly located in low and densely populated coastal areas, such as Tanjung Karang, Loli Saluran, and Labuan Bajo.
As for the results obtained from maps sourced from geospatial, several categories are divided into 3 categories with different levels of vulnerability and can be seen through the following table:

Table 12**.** Scorring parameters

Level of vulnerability	**area km2**
Somewhat steep	3.531
Steep	117,6002105
Very steep	1232,818549

The results of overlaying spatial data on land height, land elevation, slope and beach distance. Produces a Tsunami hazard zoning map which is divided into 3 colors, namely red, dark green and light green.

- The red zone indicates an area with a very high level of vulnerability, this area is very vulnerable to the impact of tsunami waves and requires special handling such as the construction of embankments or evacuation routes.
- The yellow zone indicates that the area has a medium level of vulnerability. These locations are generally located slightly further away from the coastline, but still have a risk of being impacted.
- green zones indicate low or no tsunami hazard potential. These areas are relatively safer and can be used as evacuation routes.

On the resulting map, it can be identified that zones with high hazard levels are more dominant in low and densely populated coastal areas, such as Tanjung Karang, Loli Saluran and Labuan Bajo.

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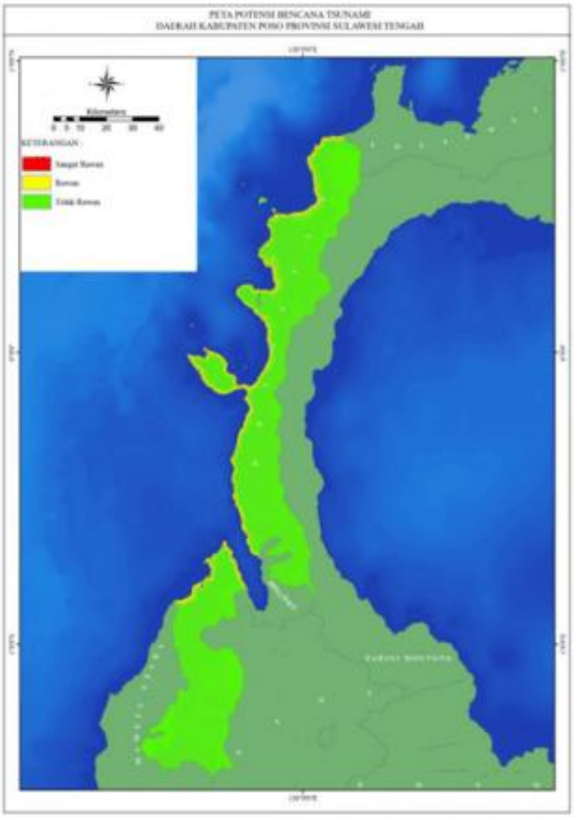

Figure 3. Tsunami-prone Map

4. CONCLUSIONS

The results showed that the coastal areas of donggala district have a high risk of tsunamis, especially low and densely populated areas such as Tanjung Karang, Loli Saluran, and Labuan Bajo. Analysis of the diversity of rock types shows high precipitation that has the potential for landslides. In addition, this study also identified the potential for liquefaction in some areas of donggala, especially inland areas near the coast and large rivers.

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