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Tectonically-Controlled Disaster Risk Assessment Study Along Palu-Koro Fault In Donggala Regency, Central Sulawesi: Record From 2018 Earthquake Effect

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ABSTRACT

One of the major tectonic manifestation in Sulawesi Island is the Palu-Koro fault which extends north-northwest to south-eastwards in the centre of the island. The presence of the Palu-Koro Fault has responsible for the series of natural disasters occurred in Central part of Sulawesi and its surrounding which include earthquake, tsunami, liquefaction and subsidence. The need for further tectonic studies and geological structure mapping surrounding the fault is very important for disaster risk reduction strategy including mitigation effort to reduce casualties affected by future disasters. The study was conducted along Palu-Koro Fault Zone in Donggala Regency, Central Sulawesi. This study aims to assess the disaster risk including vulnerability, threat and capacity that generated by tectonically-controlled process along Palu-Koro Fault in Donggala Regency due to 2018 earthquake. The methodology used includes disaster risk reduction assessment approach, field geological structure observation, satellite imagery analysis using high-resolution satellite image from the Center for Remote Sensing Technology and LAPAN (National Institute of Aeronautics and Space), Pleiades satellite imagery with a resolution of 0.5 meters and SPOT 7 satellite imagery with a resolution of 1.5 meters. The result shows that the study area is prone to tsunami, earthquake, liquefaction and subsidence processes. Tsunami, earthquake and subsidence are grouped into high-risk disaster whereas liquefaction is considered as having moderate-risk level. The results of the assessment are expected to be used as a solid basis for planning disaster risk reduction efforts in the future.

Keyword : Palu Koro Fault; Donggala Regency; Geological Structure mapping.

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INTRODUCTION

The seismic activity of the Palu-Koro Fault makes Palu City and its surrounding areas as one of the areas with a high level of vulnerability to tectonic-induced disaster including earthquake and tsunami in Indonesia. The high level of seismic activity of the Palu-Koro Fault in this region is due to its geological setting which is a collision zone for three major tectonic plates, namely Indo-Australia, Eurasia and the Pacific (Bellier O et al,2001; Maulana et al, 2020) (Figure 1). The Palu-Koro Fault extends from Palu Bay around the boundary of the Sulawesi Sea with the Makassar Strait to the south-southeast through the northern part of Central Sulawesi to the south on the northern coast of Bone Bay to the Banda Sea for about 500 km (Patria et al, 2020). The Palu-Koro Fault on the mainland runs right into the heart of Palu City (Palu Valley) and Lariang River in the Pipikoro Valley, Donggala. The fault segments continue to move relative to each other and have a sinistral-slip (leftward shift) with a dip of about 50° and an average shear velocity or slip rate of about 29 mm/year (Daryono et al, 2013)]. This fact causes high earthquake activity in the Palu area and its surroundings. In addition, the effect of the Palu-Koro Fault also causes several other faults in the vicinity, such as Poso and Matano Fault. In the context of the reconstruction and rehabilitation of the 2018 earthquake and tsunami disaster in Donggala, it is necessary to conduct a disaster risk assessment study on the tectonic – controlled disaster along the Palu – Koro Fault. The results of the study could be the basis for mitigation effort to minimize casualties, both lives and infrastructure if a natural disaster occurs in the future.

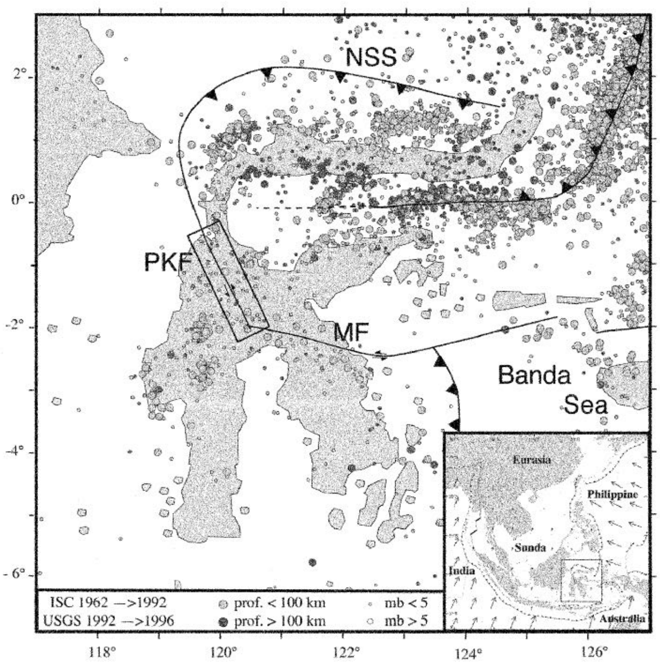

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Figure 1. Seismicity of Sulawesi and Palu-Koro Fault (PKF) [1]. NSS = North Sulawesi Subduction, MF = Matano Fault.

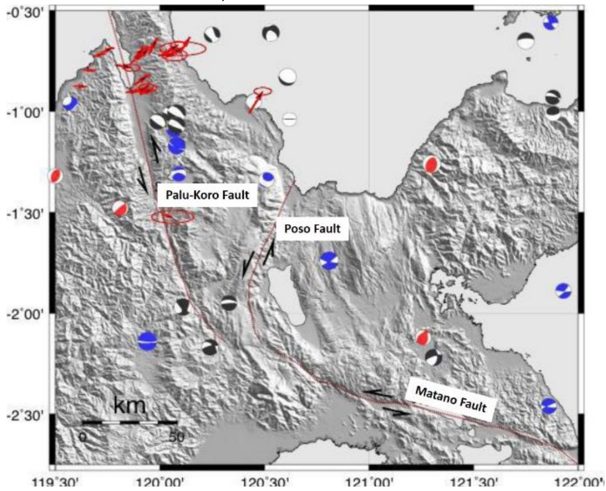

Figure 2. SRTM map showing connectivity of Palu-Koro Fault with Poso and Matano Fault and the earthquake mechanism model that occurred in the surrounding study area (Daryono et al, 2013)

METHOD

Disaster risk assessment study is conducted using disaster risk reduction model. Disasters occur as a result of the collection of hazardous components that affect nature and the environment as well as the level of vulnerability and capacity of a community in managing the threats. The higher the threat value and the vulnerability value, the higher the risk of a disaster (Sagala et al, 2021). To reduce disaster risk, it is necessary to increase the value of vulnerability to a capacity by strengthening capacity within the community in managing the environment, recognizing threats, knowing the impacts that can be caused by factors that cause disasters. Four main sampling strategies for collecting fracture data are widely used and reported in the literature: linear scanline method, areal sampling, window scanline sampling and circular scanline method (Priest and Hudson, 1981);

We use high-resolution satellite imagery to determine the distribution of disaster-affected areas using satellite imagery from the Center for Remote Sensing Technology and Data LAPAN (National Institute of Aeronautics and Space, Pleiades satellite imagery with a resolution of 0.5 meters and SPOT 7 satellite imagery with a resolution of 1.5 meters. Disaster risk studies are the basis for selecting strategies that are considered capable of reducing disaster risk. This disaster risk assessment should be able to become an adequate basis for the regions to formulate disaster management policies. To get the value of disaster risk depends on the magnitude of the threats and vulnerabilities that interact. The interaction of threats, vulnerabilities and external factors becomes the basis for conducting a disaster risk assessment of an area. (Shi et al, 2020)

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GEOLOGICAL SETTING

1. Physiography

Based on the field-collected data and analysis of satellite images, morphologically of the study area can be grouped into Coastal Plain, Sloping Plain, Moderately Steep Hills, Steep Hills and Very Steep Hills (Table 1).

Table 1. Condition of topographic slope of Donggala Regency

Slope Type	Percentage of Slope (%)	Area (Km2)	Percentage of Area (%)
Plain	0 - 8%	697	15.4
Sloping Plain	8 - 15%	476	10.5
Hilly Pretty Steep	15 - 25%	715	15.8
Steep Hilly	25 - 45%	1544	34.2
Very Steep Hilly	> 45%	1089	24.1

2. Stratigraphy

Based on rock, structure and age of the rock, the order of stratigraphic for the study area is categorized into 13 rock units as reported by previous workers [6][7][8], namely: alluvium deposits and coastal deposits, molasse Sarasin deposits, coral limestones, sandstones of the Pasangkayu Formation, conglomerates and sandstones of the Lariang Formation, Kambuno granite, intrusive rocks of the Tinombo Formation, slate and phyllite of the Latimojong Formation, marble and meta claystone, schist and genes of the Metamorphic Complex, and diorite and granodiorite intrusions (Figure 3)

3. Geological Structure

The major geological structure of the island of Sulawesi includes the Palu-Koro Fault, Walanae Fault, Matano Fault, Batui Fault, Poso Normal Fault, Balantak Fault, Gorontalo Fault, North Sulawesi Subduction, and Bone Bay (Walpersdorf et al, 1998; Sukamto and Simanjuntak, 1983). The regional geological structure is dominated by the Palu-Koro Fault which is trending north-northwest-southeast and the interaction of the main plate confluence from the north-west and southeast, resulting in the formation of a minor fault lineament. On land, this fault is characterized by the presence of a fault valley which is flat at the bottom, with a width of up to 5 km around Palu, and its walls reach a height of 1,500 – 2,000 m above the valley floor, while at sea it is characterized by its steepness bathymetric. According to [Van Leeuwen et al, 2015] this fault

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stretches from the west of Palu City to Bone Bay which is approximately 250 km long, with a transcurrent movement speed of about 2 - 3.5 mm to 14 - 17 mm / year. It is mentioned that the fault showed a leftward shift and GPS (Global Positioning System) interferometry analysis showed a leftward shift up at a rate of 3.4 mm/year (Walpersdorf et al, 1998). The Palu-Koro Fault cuts through the western and central section of Sulawesi, continuing to the north to the North Sulawesi Trench which is the continental margin situated in the Sulawesi Sea (Sukamto and Simanjuntak, 1983). The Palu-Koro Fault is a sinistral horizontal fault with a displacement of more than 750 km.

RESULT AND DISCUSSION

1. Tsunami

The history of the tsunami along Palu-Koro Fault Zone in Donggala Regency and its surroundings has occurred about 5 times from 1927-2018 with magnitudes ranging from 6.3-7.7 (Table 2). Based on the history of the tsunami, a scenario analysis was carried out to simulate re-prediction of occurrences by taking 4 location points each in 1927 representing the southern part, 1968 representing the northern part of Donggala Regency and 2018 (two points: Sirenja coastal and Palu/Pantoloan Bay). The level of Tsunami disaster risk in Donggala Regency based on the results of a disaster risk assessment show a high level of the tsunami threat, high vulnerability and low capacity (Table 3 - 6). Over all, Donggala Regency has a High risk of Tsunami (Fig. 4a).

Table 2. Historical data for earthquake occurrences causing a tsunami and its impact in Donggala regency [USGS, 2018]

Year	Date dd/mm	Latitude (S, N)	Longitude (E)	Magnitude (M)	Wave Height	Location
1927	01/12	0.7°S	119.7°	6.3	15	Tanjung Banawa
1938	19/05	1°S	120°	7.6	3	Kab. Sigi
1968	14/08	0.7°N	119.8°	7.4	10	Sindue
1996	01/01	0.83°N	120.01°	7.7	3,4	Sojol
2018	11/27	0.256°S	119.846°	7.4	10	Sirenja

2. Earthquake

Seismicity data from earthquakes in Donggala Regency that have occurred in the 1927-2020 period show a magnitude range of 5 to 7.7 or are in the MMI (Modified Mercalli Intensity) range VI to IX (USGS, 2018). In addition, the character of earthquakes in this area always has an initial earthquake strength with a magnitude of 5-6 (foreshock) the main earthquake with a magnitude range of 7-8 (mainshock) and decreases slowly to a magnitude of 4-5 (aftershock) in a short-range (hours) some of the active vulnerabilities are always triggered by faults (Jaya et al,

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2019). This area is highly potential for earthquakes that can trigger multiple disasters such as tsunamis, liquefaction, land subsidence and landslides .

The results of fracture accumulation data analysis (joints and minor faults) show that the faults most potential to trigger earthquakes are oblique faults which are progressive from horizontal faults (Nicol et al, 2016). The joint scan results from 8 observation points showed high intensity on average = 20 – 60 mm (very close spacing). Based on the analysis of magnitude, MMI intensity and fracture patterns in the Donggala area, the earthquake vulnerability is high (Table 3). The level of earthquake risk in Donggala Regency is based on the results of a disaster study that shows a high level of threat, high vulnerability and low capacity, Donggala Regency has a high risk of earthquakes (Fig. 4b).

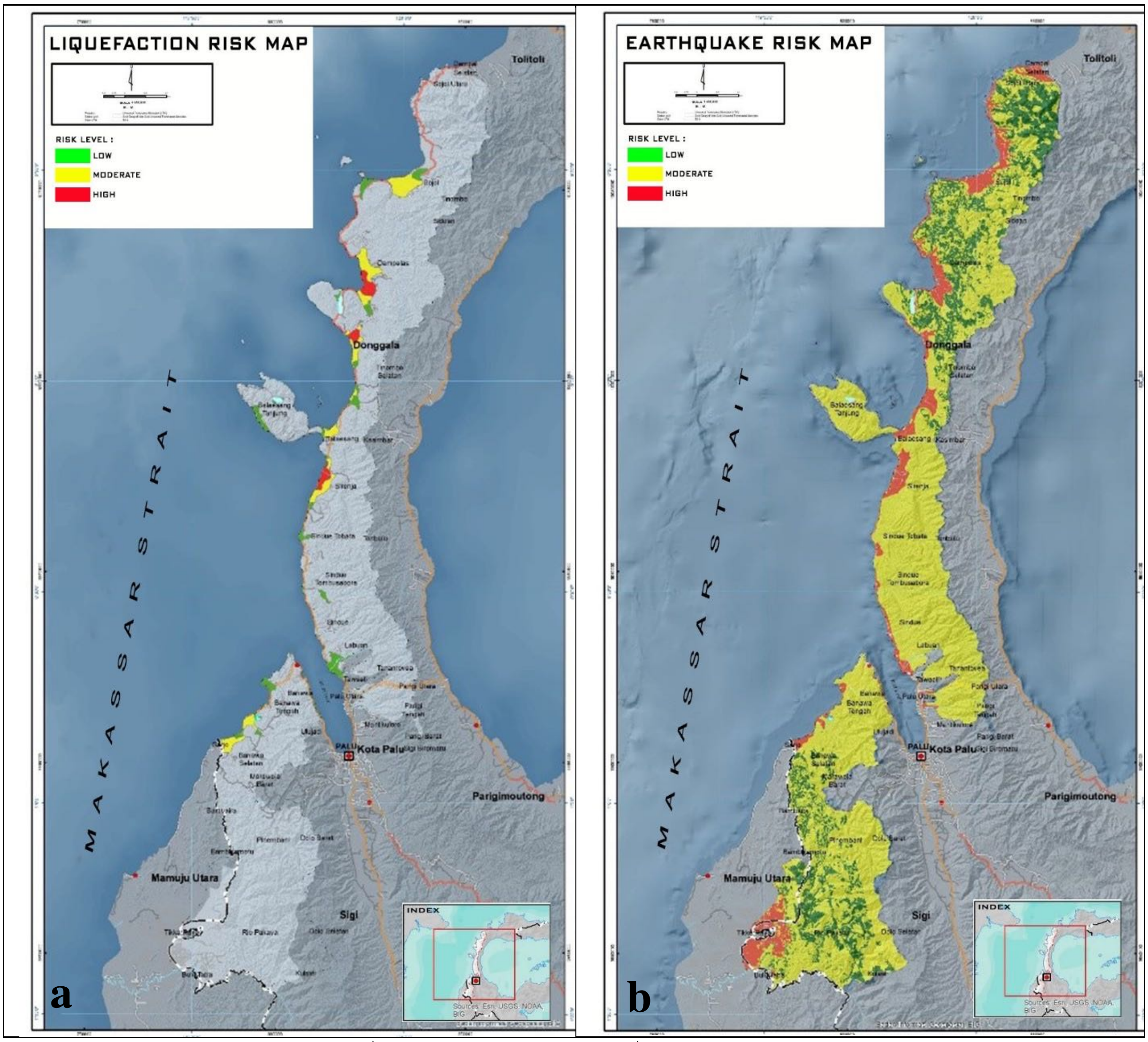

Figure 3. a) Tsunami Risk map; b) Earthquake risk map

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3. Liquefaction

The Donggala area has liquefaction potential since the area being adjacent to Palu and Sigi areas which have been proven to have liquefaction during the 2018 earthquake, including Petobo, Sirenja. Rock characteristics and regional typology have similarities and are geometrically located in a series of fault zones and damage fault of the active Palu-Koro fault. The field observations indicate that several areas in this area have the potential for liquefaction due to the following characteristics:

(1) Alluvial soils (sand, silt and clay) that are not well consolidated are encountered in many valleys and slopes, such as on the coast along the West coast of Donggala Regency; (2) Earthquake intensity (5-8 Mw) and high vibration intensity (MMI V-IX), if there is strong vibration and shaking in this range, it will easily trigger soil slurry; (3) high groundwater conditions (types of surface water and shallow groundwater types and water saturation in coastal areas); (4) Some places have shown vertical displacement and soil structure damage, crack and fractured, such as the coast of Lero and Sirenja; (5) The emergence of sand boils in several locations after the 2018 Palu earthquake, such as in the Dampal area (Fig. 4).

Figure 4. Occurrences of liquefaction in Dampal area as shown by intensive fracture of alluvial rock, a) soil subsidence, and b) surface water pushing the material to appear on the surface in the form of a sand boil

The results of the spatial analysis portray two categories of liquefaction zones in this area, namely: (1) Medium vulnerability zone: zones that are likely to experience liquefaction, have symptoms 1-3. (2) Low zone: bedrock. Although there are indications of liquefaction symptoms accompanied by land subsidence, which is generally only found in coastal areas. The level of risk of liquefaction disaster in Donggala Regency based on the results of the liquefaction disaster risk study, the level of threat to liquefaction disaster is medium, vulnerability is medium and capacity

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is low, Donggala Regency has a moderate risk of liquefaction (Table 3-6). Liquefaction risk map can be seen in Fig. 5a.

4. Land subsidence

The field survey shows two areas that have clearly experienced land subsidence and are generally located on the coast of Donggala Regency. The results of direct measurements in the field show that there has been a decrease of 1.2 m. The area that experienced subsidence includes Lero Village = 7.67 Ha and in Tompe Village = 70 Ha (Figure 5b). Based on the disaster risk assessment, it is concluded that Donggala Regency has a high Subsidence threat index, has a moderate level of vulnerability and a low-capacity index, thus Donggala Regency has a high Subsidence threat level (Table 3-6).

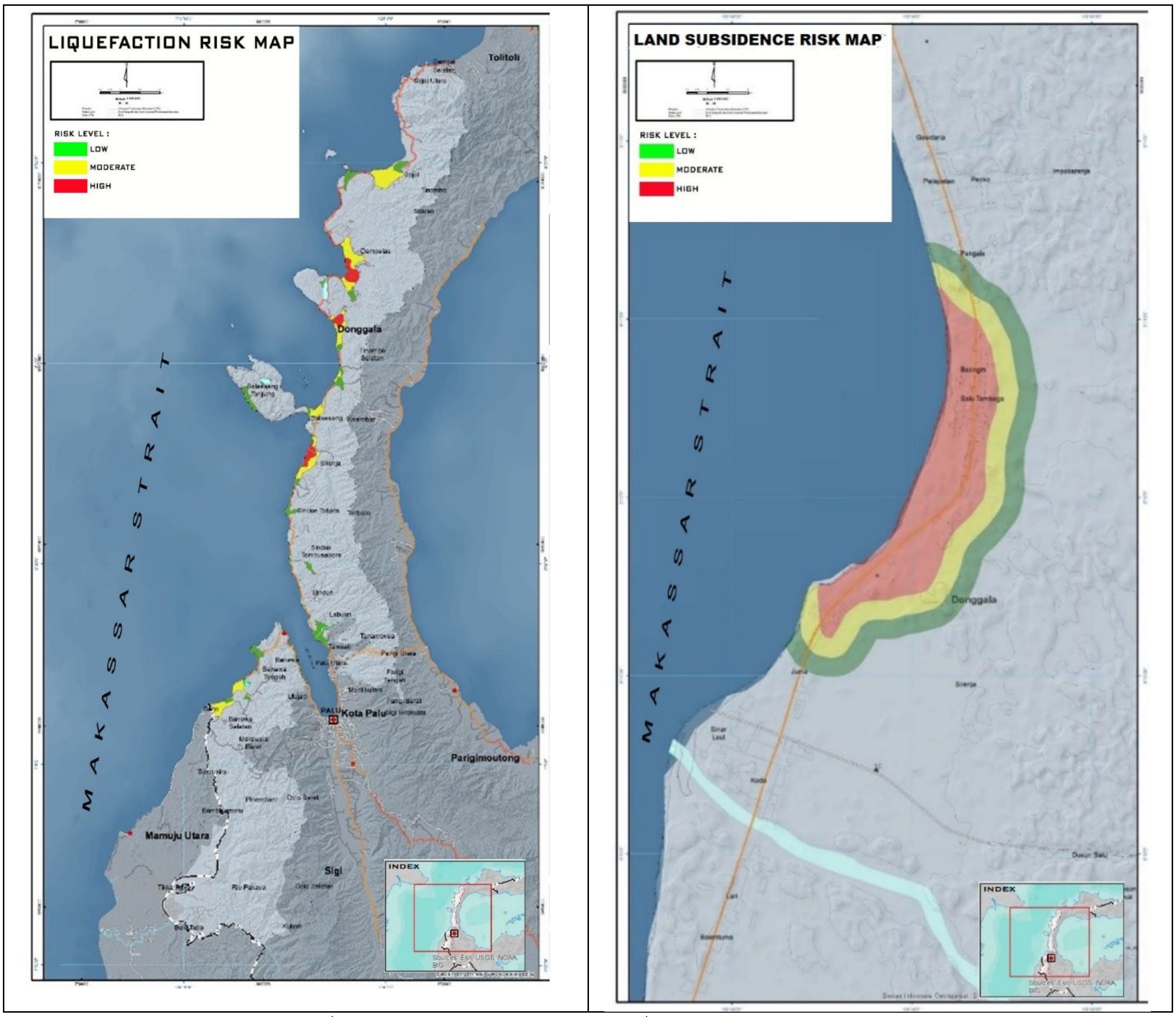

Figure 5. a) Liquefaction Risk map; b) Land subsidence risk map

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Table 3 Disaster threat level in Donggala regency Central Sulawesi

Threat Level		Population Exposure Index (Soul)		
		Low	Medium	High
Threat Index	Low	-	-	-
	Medium	-	Liquefaction, Subsidence	-
	High	-	-	Earthquake, Tsunami

Table 4 Levels of losses due to disasters in Donggala Regency, Central Sulawesi

Threat Level		Population Exposure Index (Soul)		
		Low	Medium	High
Threat Index	Low	-	-	-
	Medium	-	Liquefaction, Subsidence	-
	High	-	-	Earthquake, Tsunami

Table 5 Capacity level of Donggala regency, Central Sulawesi

Threat Level		Population Exposure Index (Soul)		
		Low	Medium	High
Threat Index	Low	-	-	-
	Medium	-	-	Liquefaction, Subsidence
	High	-	-	Earthquake, Tsunami

Table 6 Disaster risk level Donggala regency Central Sulawesi

Threat Level		Population Exposure Index (Soul)		
		Low	Medium	High
Threat Index	Low	-	-	-
	Medium	-	Liquefaction, Subsidence	-
	High	-	-	Earthquake, Tsunami

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CONCLUSION

From the field data, laboratory analysis and risk assessment, it can be concluded that the potential disasters that could occur in Donggala area are tsunamis, earthquakes, liquefaction, and subsidence. Tsunami, earthquake and subsidence show a high level of the threat, high vulnerability and low capacity and therefore Donggala Regency has a high risk of tsunami, earthquake and subsidence. Liquefaction is considered as having moderate-risk level. The results of the assessment are expected to be used as a solid basis for planning disaster risk reduction efforts.

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