Liquefaction and normal fault in Talise Valangguni and Tanamodindi Villages of Palu City; a preliminary observation of impact MW 7.5 earthquake in 2018 at Central Sulawesi Province, Indonesia

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Abstract. Talise Valangguni and Tanamodindi Village are among the areas that affected by 28 September 2018 earthquake. This fact-based on our findings about ground surface deformation, the liquefaction and normal fault surface rupture effect. We then make further observations to record the existing hazard characteristics and delineate the affected area to see the hazards configuration to geological factors. The results showed there were 5 liquefaction areas with about 0.13-1.29 km². The liquefaction effect characteristics that we found are fracture, downlift-uplift, wavy surface, sudden stagnant water, and lateral spreading. Liquefaction sites in this area are identical in seasonal river routes and strongly influenced by lithological, hydrogeological, and earthquake. The sediment deposits are dominated by saturated sand, which can experience significant infiltration, worsening the soil strength size. As a result, this area is susceptible to liquefaction effects when strong earthquakes occur. Meanwhile, normal faults are ± 1.5 km long, oriented west-east, where the southern block has decreased between 5-30 cm. We suspect that this fault existed before the earthquake and appear on the surface after the quake, contributed by shocks and gravity. We hope that this information can be used as a reference for spatial planning for Palu City in disaster mitigation.

1. Introduction

Palu is an area with a high seismicity level, which is in the water-saturated quaternary sediment deposits. This seismicity makes the Palu area vulnerable to liquefaction [7, 27], and has been proven in the Mw 7.5 earthquake incident on September 28, 2018. Regarding this, quite a lot of research results and disaster reports have been reported. Where in almost all Palu Valley areas, there was a liquefaction effect with different levels of damage.

The four most highlighted liquefaction locations are Balaroa and Petobo in Palu City, Jono Oge and Sibalaya in Sigi Regency, which is considered to be areas of liquefaction that induce large-scale ground motion phenomena [3, 6, 8, 10, 12, 13, 14, 20, 21, 24, 26]. The liquefaction effect also occurs on the Palu Bay [17] and the Palu-Koro fault surface rupture border [1]. However, it seems that the published information on liquefaction in the Palu area has not delineated several other affected areas. Therefore, we report in this article to add information on other liquefaction locations in the Palu area, namely Talise Valangguni and Tanamodindi Village. These areas were also severely affected by liquefaction, besides that, there was also a surface rupture fault, but they were not exposed. We found
this out after conducting a preliminary survey and finding ground surface deformation, which characterizes these two phenomena, which has caused massive damage to buildings and other infrastructure. This paper will focus on describing and mapping the two types of geological hazards, and we hope that this information can contribute to mitigating natural disasters efforts and utilization of land use in Talise Valangguni and Tanamodindi, Palu City.

2. Methods
This study is a preliminary survey that maps and describes the impact of the Mw 7.5 earthquake in 2018, in Talises Valangguni and Tanamodindi Villages in Palu City (Figure 1a). This impact is an earthquake derivative hazard in the form of liquefaction effects and surface rupture of normal faults that cause deformation of the land surface, thus having a significant impact on surrounding settlements. Data collection was carried out by direct observation at the location of the incident. We reviewed, examined, and interpreted the deformation's characteristics present, then delineated to see the configuration of the liquefaction site and the continuity of the surface rupture fault path. We conduct a qualitative holistic evaluation of this hazard causes phenomenon and provide an overview of its impact. Integrate the results of field observations with existing literature materials, such as geological maps, hydrogeological maps, seismic information, and several references to other related publications. That way, this paper can be said to be like a report that can provide information about the history of geological hazard events that have occurred in the area.

3. Results and Discussion
3.1 Regional geology of Palu area
The Palu area is shaped like a basin or a valley form, known as Palu Valley (Fossa Sarasina). Physiographically, it looks like the morphology of the graben structure, where two high ridges flank the valley on the west and east sides. On the west side, the altitude is more than 2,000 m.asl, higher than the eastern side with an altitude between 400-1,900 m.asl [19]. The morphology of the Palu area divided into 3 (three) units, namely lowlands, hills, and mountains. Lowland, occupying the coastal area and the Palu basin with an elevation ranging from 0-50 m.asl which shows a sloping to flat topography. The hills area occupies the plain and the mountains with a range of 50-800 m.asl, with a diagonal topographical feature of steep to steep slopes. Meanwhile, mountainous areas occupy the western and eastern parts that extend from south to north with an altitude ranging from 800 - 2,000 m.asl (See Figure 1d).

The rock formations in the Palu area and its surroundings consist of alluvium and coastal deposits (Qap), molasses Celebes Sarasin and Sarasin (1901) (QTms), TinomboAhlburg formation (1913) (Tt), metamorphic rock complexes (km), and intrusion rock (gr) (see Figure 1b). Among the 5 formations, only Molasa Celebes Sarasin and Sarasin (1901) (QTms) alluvium and coastal sediment (Qap) in the study area. The Molas Celebes Sarasin and Sarasin Formations (1901) (QTms) are at a lower altitude on the sides of the two embankments, overlapping the TinomboAhlburg Formation (1913) (Tt) and the Metamorphic Rock Complex (km), containing rubble originating from the formations are older and consist of conglomerates, sandstones, mudstones, coral limestones, and marls, all of which harden. Near the metamorphic rock complex in the eastern ridge's western part, the deposit consists mainly of coarse lumps and is presumably deposited near the fault. The rocks towards the sea turn into more sufficient grained clastic rocks. This layer shows the middle Miocene age. Then, alluvium and coastal sediment (Qap) consisting of gravel, sand, mud, and coral limestone, formed in the environment of rivers, deltas, and shallow seas, are the youngest sediments in this area. The deposits may have been entirely Holocene in age [19].

From the hydrogeological aspect (see Figure 1c), the moderate to high productive aquifer zones are on the alluvium plains and coastal sediments (Qap), and some are scattered in the Molasa Celebes Sarasin and Sarasin Formations (1901) (QTms). This area is also a groundwater basin [15]. The groundwater level is free between 1-5 m from the local land elevation, the potential aquifer is between 50-75 meters depth, and the discharge of springs that appear on the surface is between 30-50 L/s [2].
Figure 1. Administrative boundary maps, geology, hydrogeology, and topography

The Palu-Koro fault controls the geological structure of the Palu area. This fault is an active fault, forming a system of segmented shear fault zones. Still, overall the fault type around the site is not pure strike-slip but is oblique because the fault scarp is very visible as a dip-slip component, based on the analysis of morphological features along the Palu-Koro fault trail in the southern part of the Palu Valley. [5]. The Palu-Koro fault has a characteristic steep slope morphology, characterized by triangular facets and tectonic hills. There is a vertical component in some left-lateral strike-slip sites that intersects the strike-slip element with the normal part. From the Mw 7.5 earthquake in 2018, the main Palu-Koro fault line can be scanned based on the surface rupture path's appearance. This route crosses the district of Sigi, Palu City, and Palu Bay then continues north to the neck region of the western part of Sulawesi Island, which administratively belongs to Donggala Regency [1, 24]. The maximum slip of the Palu-Koro fault was 6 ± 0.5 m in the vicinity of Palu City, and an average of 1.9 m to 4.7 m in the northern and southern regions of Palu City [4].
3.2 Liquefaction and normal fault

One of the effects of earthquake derivatives is the liquefaction event. The location of liquefaction can only be identified based on the effect of deformation on the surface, such as downlift / subsidence, uplift, fracture, there is stagnant water originating from below the surface, the presence of dunes, and sand boils, or the ground looks like burying [9], it can even induce the occurrence of lateral spreading and land movement.

According to Seed and Idriss [19], liquefaction will occur in areas prone to strong earthquakes, composed of water-saturated sand deposits with low density, or in areas where co-seismic surface movement exceeds the threshold value. These criteria are found in the Palu area, where this area has earthquakes prone at levels VIII to X on the MMI scale, it means that earthquake shocks in this area can occur very strongly to the extreme [7]. Then, the Palu Valley is a sedimentary deposit area [19], located in a zone of medium and high productive aquifers [2], which is also defined as a groundwater basin [15]. Under these conditions, this area is very susceptible to liquefaction events during strong earthquakes. This event is evident on September 28, 2018, where almost all areas of the Palu Valley and other quarterly sedimentary basins have experienced liquefaction, where; one of the affected areas is the Talise Valangguni and Tanamodindi Village, in Palu City. However, liquefaction in this area is strongly influenced by lithological, hydrogeological, and earthquake factors. This area's preconditions are young, sandy, and quickly saturated geological formations [22, 28, 29]. However, more specifically, the identical liquefaction sites are in the seasonal river channel (see Figure 2-3, Table 1). It is important to report, however, that it appears that fractures, uplift-downlift, and lateral spreading are scattered in the river basin.

![Figure 2. Map of liquefaction and normal fault locations](image-url)
Liquefaction can occur in sedimentary deposits that are predominantly saturated sand around water bodies [25], in this case, rivers. Even though the rivers in this area are seasonal, the water supply during heavy rains will also fill the river floodplain area. Then, infiltration occurs quickly, filling the pore spaces in the sediment deposits around the river. This process then increases the pressure on the porous medium, which comes from the grain space that has been filled with fluid, causing the bonds between the grains to weaken (loose). The infiltration may repeat significantly with the intensity of the rain, which worsens the size of the soil strength; as a result, this area is susceptible to liquefaction effects when subjected to strong shaking.

Apart from the liquefaction effect, another inherited hazard is the surface rupture of the fault section. Its appearance indicates displacement or shifting between blocks of soil and/or rock [11, 16]. There is no previous reference which states that there is a fault in this area. However, we suspect that this fault existed before the earthquake, based on the shape of the morphological relief. The match fault’s continuity is at points of significant elevation differences, and the southern block section has decreased between 5-30 cm, which indicates the fault type is a normal fault, right on the fault line. The surface rupture trail of the fault that we encountered was quite long; namely ± 1.5 km, oriented west-
east, crossing perpendicular to Merpati street and Merpati II street, in the Tanamodindi Village, which along the path of this fault has damaged the houses of residents in its path (see Figure 4-5).

Table 1. Characteristic and impact of liquefaction area

| Location       | Characteristic at surface                                                                 | Impact                                                                 |
|----------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Talise Vallangguni-1, (TS-1), Area ± 1.29 km² | Lateral spreading, fracture, and downlift. The size of the open land is between 5-50 cm, occurs on sandy to gravel soil. Suddenly stagnant water was found that did not come from rain | Office buildings, business premises and residents' houses were severely damaged. Residents' houses are tilted, descended, damaged, and collapsed due to lateral spreading, fracture and downlift. Combined with shocks from the earthquake. |
| Talise Vallangguni-2, (TS-2), Area ± 0.35 km² | Fracture, with ± 15 cm wide opening. The shape of the ground surface also looks bumpy, due to the uplift and downlift |                                                                       |
| Tanamodindi-3, (T-3), Area ± 0.43 km² | The middle part of the area underwent subsidence, limited by a fracture where one part decreased by about 1-2 cm. |                                                                       |
| Tanamodindi-4, (T-4), Area ± 0.31 km² | Lateral spreading, fracture, and downlift. Open land size between 10-30 cm, occurs in sandy to gravel soil. |                                                                       |
| Tanamodindi-5, (T-5), Area ± 0.13 km² | Fracture and downlift, descending about 50 cm with a width of about 7 meters. |                                                                       |

It is known that the Palu-Koro fault is a system of shear fault zones [23], where there are many segments within the zone, and possibly this fault. However, this fault is not the source of the earthquake, such as the main Palu-Koro fault line, but the impact of the earthquake itself. In other words, these normal faults could have been formed due to strong shaking, and the gravitational pull also contributed to one of the fall blocks.

Figure 4. Morphological relief map around the normal fault continuation path
4. Conclusion

Talise Valangguni and Tanamodindi Subdistrict in Palu City are severely affected by the danger of the Mw 7.5 earthquake derivative in 2018, namely the effects of liquefaction and the surface rupture of the fault. It seems that geological, hydrogeological, seismic, and specific conditions around the river path have played an important role in this phenomenon's presence. It is important to report that it appears that fractures, uplift-downlift, and lateral spreading are scattered in the river basin. However, it is regrettable that the development area in this subdistrict has not paid close attention to the existence of these hazards before, by building on dry river boundaries in geological formations that are prone to liquefaction. We report this incident because it is necessary to pay attention to the threat of seismic hazards. The same disaster may still occur in the existing area in the future. Of course, existing buildings such as residents' houses, business premises, and other facilities need to be considered. Thus, there must be guarantees and an assessment of the consequences of land use, with all the possibilities that are based on the size of the incident, as we have reported.
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