Spatial analysis of the liquefaction vulnerability zone based on the phreatic level at the Palu groundwater basin, Central Sulawesi Province

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Abstract. An earthquake with a magnitude of 7.4 in Palu City and Donggala District in Central Sulawesi Province on September 28, 2018 has caused a liquefaction disaster. Basically liquefaction can occur in earthquake prone areas, shallow phreatic depth and poorly consolidated soil. This study attempts to examine the relationship between phreatic depth and the probability of liquefaction. The research method is an analog and numerical relation model, by combining the aquifer system model and groundwater geographic information system with landuse patterns in areas affected by liquefaction disasters. This method is described in Spatial and Environmental Analysis, which is supported by the use of satellite imagery and the analysis process with the Arc View Gis 3.3 program. The results showed that there was an influence between rainfall on the spatial distribution of phreatic depth, with the average rainfall in the Palu area being 68.74 mm / month and the depth of phreatic level ranged from medium (2.5 - 7.0 meters from ground level) - shallow (<2.5 meters from ground level). Based on the phreatic depth of the Palu groundwater basin, the chances for liquefaction are in the medium to high zone class.

1. Introduction
The Palu region in Central Sulawesi Province is one of the areas that often occur in earthquakes with high seismicity. Based on the 1909 earthquake study in the Saluki segment of the Sigi Regency, it was predicted that the Central Sulawesi earthquake had a potential cycle and an estimated earthquake strength occurred every 130 years with a power range of 6 to 7 on the Richter scale [1]. The earthquake that shook Palu and Donggala in Central Sulawesi on September 28, 2018, also caused the phenomenon of liquidity or the local language "nalodo". There are recorded thousands of houses affected by liquefaction, especially in the Petobo and Balaroa areas [2], [3].

The phreatic depth phenomenon is very closely related to the chances of liquefaction. Groundwater is present in a rock within a geological basin boundary[4], [5]. Groundwater basins are a hydrogeological unit consisting of one or several interconnected aquifer parts forming a system and can change due to environmental changes [6], [7], [8]. Quantitative estimation of water resources is important and can be done by water adsorption and balance techniques [9]. Figure 1 shows groundwater model in basin. The groundwater basin is an area with water originating from surface runoff. Groundwater basins are one
example of a geomorphological system [10], [11], [12]. The use of geomorphological systems is very appropriate to show the relationship between parts of the system in an object. Groundwater flow system is influenced by several factors. [13] added that groundwater flow is caused by fluid potential differences. They showed a mathematical model of a groundwater fixed flow system based on the Laplace equation. In this model, groundwater flow patterns can be identified hypothetically both geologically isotropically and homogeneously with topographic changes as specific areas called pressure limits [14], [15], [16].

![Figure 1. Groundwater Inclusion Model in Basins](image1)

![Figure 2. Liquefaction Model](image2)

Liquefaction modelled in figure 2 is a phenomenon where the strength and stiffness of the soil decreases due to earthquake or other ground movements. This occurrence is a process or event that changes the nature of the soil from a solid state to a liquid state, which is caused by a cyclic load at the time of an earthquake so that the pore pressure rises near or exceeds the vertical stress [3]. Potential
liquefaction soils are generally composed of material dominated by sand size. The effect of liquefaction is also sometimes different if the friction strength of the soil has not been exceeded, the pore water pressure that rises is strong enough, only resulting in cracks in the soil and from the cracks will appear water carrying sand material. Factors influencing the occurrence of liquefaction: vibration characteristics, soil type, groundwater or phreatic level, grain diameter distribution, initial density, drainage and deposit dimensions as well as drainage ability [3], [16].

Related to the relationship of groundwater density with aquifers, [6], [17] explains that groundwater is stored in a layer of rock that can store and pass water called aquifers. The geological structure of the Palu basin consists of faults, alignment and unconformity as the main geological structure which is dominated by graben structures known as the Palu Koro Fault [18], [19]. The existence of lineament structure in the Palu Koro fault affects the earthquake potential and groundwater density [20], [21]. This condition will affect the physical and chemical characteristics of groundwater which will affect the quality of groundwater in the aquifer system [22], [23]. This study attempts to examine the relationship of phreatic depth in aquifer systems with the likelihood of liquefaction[24], [25]. The figure 3 shows the model of phreatic flow of groundwater.

![Phreatic Flow Model](image)

**Figure 3.** Phreatic Flow Model

2. Materials and Methods
The research location at the Palu groundwater basin in Central Sulawesi Province, administratively covers part of Palu City, Donggala and Sigi Regencies (figure 4). This study aims to determine the phreatic depth as one of the determining parameters for liquefaction [26]. The phreatic level is the water level measured from the ground surface [27]. The research method is an analog and numerical relation model, by combining the aquifer system model and groundwater geographic information system with land use patterns in areas affected by liquefaction disasters [28], [29]. This method is described in Spatial and Environmental Analysis, which is supported by the use of satellite imagery and the analysis process with the Arc View Gis 3.3 program.

The tools used in this study include measuring tape, GPS and Arc Map. The materials used include the Indonesian Earth Map scale of 1: 25,000 sheets of Palu, the Geological Map of scale 1: 100,000 sheets of Palu, and the Semi Detailed Land Map scale of 1: 50,000 in the Palu area. Secondary data used include rainfall data and the location of the rain station. The depth of the groundwater level is obtained by making direct measurements on a number of dug well points.
3. Results and Discussion

Groundwater Basin is genetically a unit of landform formed by fluvial and denudational origin. A hydromorphological unit is a unit of landform that specifically characterizes the characteristics of the Palu Groundwater Basin. Based on the geological conditions in each hydrogeological unit, that the vertical distribution of the aquifer is in the Alluvium and Pakuli Formation. The lithology comprising aquifers consists of: gravel, sand, clay, silt, gravel sand, sandy gravel and clay sand, which are productive aquifers.

Determination of the amount and availability of groundwater is estimated quantitatively by the percentage rainfall method, using monthly rainfall data - an average of the last 5 years (2010-2015) from 3 observation stations namely: Meteorological and Geophysical Station, Mutiara Airport, Palu City, BPP Mantikole Station Donggala Regency and Wuno Sub-watershed Station, Sigi Regency. Furthermore, in figure 5, it can be seen that the average monthly rainfall in Palu Groundwater Basin fluctuates throughout the year. The highest average rainfall in April was 102.8 mm/month while the lowest in February was 37.7 mm/month. There is an influence between rainfall on the groundwater spatial distribution. The average rainfall in the Palu area is 68.74 mm / month. The annual average rainfall in Palu Groundwater Basin is 875.4 mm / year. The average rainfall data from the Mutiara Meteorology Station and the Wuno Sub-watershed Station show that the amount of rainfall that fell in the east was 924.25 mm/year while in the western part of the Mantikole BPP Station was 977.60 mm / year.

Based on the results of interpolation and analysis of field data, it turns out there is a correlation between geomorphological and geological conditions with groundwater depth. Analysis based on the average phreatic level in the dry and rainy seasons. The depth zone of the free groundwater level ranges from moderate to shallow. In the western groundwater basin, the depth of the shallow phreatic level is
60% while in the eastern part is 75%. The alluvial plain and flood plain are areas that are directed by groundwater flow. This area has a shallow phreatic level (<2.5 m from ground level). In figure 6, the results showed that the depth of the phreatic level ranged from medium (2.5 - 7.0 meters from ground level) - shallow (<2.5 meters from ground level). The shallow phreatic face distillation (<2.50 m/s) almost covers the entire Palu Groundwater Basin except in the Gumbasa area with a moderate phreatic face which is + 2.70 m/s. Groundwater with moderate phreatic surface depth (2.5-7.0 m) can dominate the eastern groundwater basin in the sub-districts: East Palu, South Palu, Biromaru and Gumbasa. The medium phreatic level (2.5 - 7.0 m from ground level) is also found locally in the districts of West Dolo and South Dolo, in the western groundwater basin. Based on geomorphological conditions, it is in the form of alluvial plains, flood plains, and denudational hills, in the Alluvium and Pakuli Formations. The lithology making up the aquifer consists of: sand, clay sand, and gravel sand.

![Figure 5. Average Monthly Rainfall at the Palu Groundwater Basin](image1)

![Figure 6. Phreatic Depth at the Palu Groundwater Basin](image2)

In figure 7 shows a map of the distribution of phreatic level in Palu Groundwater Basin, which ranges from medium to shallow classes. The phreatic level of the depth of the fluctuates on the western and the eastern Palu Groundwater Basin.
4. Conclusion
Depth of phreatic is the depth of the water table measured from the ground surface. Based on the analysis of field data from the results of measurements of 50 dug wells in the western Palu Groundwater Basin and 50 in the east, geomorphological and geological conditions affect the depth of the phreatic level. The depth of the phreatic level ranges from moderate (2.5 - 7.0 meters from ground level) - shallow (<2.5 meters from ground level). The shallow phreatic face distillation (<2.50 m/s) almost covers the entire Palu Groundwater Basin except in the Gumbasa area with a medium phreatic face which is +2.70 m/s. Based on the phreatic depth of the Palu Groundwater Basin, the chances for liquefaction are in the medium to high zone class.

![Figure 7. Map of the Phreatic Level at the Palu Groundwater Basin](image)
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