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Geospatial Liquefaction of Balaroa Area Based on Before Characteristic Hydrogeology and After Disaster Geoelecteric Measurements at Palu, Central Sulawesi Province, Indonesia

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Abstract
The liquefaction phenomenon that occurred in the Balaroa area on September 28, 2018 has caused changes in the condition of unconfined groundwater, especially the position of the groundwater table.This study aims to assess the liquefaction vulnerability of the Balaroa area based on beforedisaster hydrogeological characteristics and afterdisaster geoelectric measurement analysis in relation to groundwater potential for clean water. This study aims to predict the level of vulnerability of the Balaroa area to liquefaction based on hydrogeological characteristics in relation to sustainable clean water management. The research methods are: 1). The hydrogeological complex and setting (HCS) method by determining beforedisaster The research methods are: 1). Hydrogeological complex and setting (HCS) method by determining beforedisaster hydrogeological characteristics based on 25 observation wells to map groundwater potential zones, and 2). Hydrogeology and liquefaction prediction based on Wenner configuration geoelectric measurement analysis at 1 observation point. The results of the study show that: 1). The results of beforedisaster liquefaction measurements, the distribution of phreatic surface depth in CAT Palu, ranges from moderate (2.5 - 7.0 meters dpt) - shallow (<2.5 meters dpt). The shallowest phreatic surface distribution (1.38 meters dpt) is in West Palu District, namely Balaroa and 2) The liquefaction zone is at a depth of ≤ 18.5 meters. From the 2D geoelectric results in this area, the small resistivity value is ≤ 2 Ωm, this small resistivity value is identified as a zone saturated with fluid (water) and hydrogeologically, a productive aquifer. It can be concluded that hydrogeological characteristics are very important for determining liquefaction vulnerability zones.

Keywords:*geoelectricity, geospatial, groundwater, liquefaction vulnerability*

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I. Introduction

One of the sectors impacted by the earthquake and liquefaction on September 28, 2018, in Balaroa, Palu City, Central Sulawesi, was the clean water services sector. The liquefaction phenomenon that occurred in the Balaroa area on September 28, 2018, caused changes in the condition of unconfined groundwater, especially the position of the groundwater table (depression cone) [1], [2]. Data from the National Disaster Management Agency (BNPB) shows that the liquefaction that occurred at this location damaged approximately 40 hectares of land and destroyed 1,357 buildings. Essentially, groundwater in the Palu Groundwater Basin is a highly vulnerable physical environment phenomenon, requiring protection of its quantity and quality [3], [4], [5]. On the other hand, the presence of unconfined groundwater provides significant positive value in meeting the clean water needs of the population [6]. [7]. However, on the other hand, when the aquifer is saturated with water and is not followed by proper spatial planning, it can have fatal consequences, namely, a liquefaction disaster [8]. Based on this, this study aims to map the vulnerability of the Balaroa area to liquefaction based on before disaster hydrogeological characteristics and analysis of after disaster geoelectric measurement results in relation to sustainable clean water management.The National Disaster Management Agency (BNPB) stated that the earthquake and tsunami that struck Palu City and its surrounding areas on September 28, 2018, caused several areas, such as Petobo and Balaroa Sub-districts, to experience a natural phenomenon called liquefaction [9]. Development of an area clearly requires consideration of clean water sources. However, the liquefaction phenomenon that occurred in the disaster area, particularly Balaroa, is thought to have caused changes in groundwater levels. On the other hand, the imbalance between clean water supply and demand is a complex problem in water management in the Palu CAT, particularly in Palu City [11], [12]. Land use without considering the capacity and condition of the aquifer in the area can impact liquefaction [10], [13]. The research questions are as follows why are the hydrogeological characteristics of the Balaroa area before the liquefaction disaster and the hydrostratigraphy of the aquifer based on geoelectrical measurements using the Wenner configuration.

Figure 1: Impact of the 2018 Palu Earthquake on Balaroa

The Palu Valley and part of the western part of Sulawesi Island Neck are areas traversed by the Palu-Koro fault zone [14],[15]. This fault is oriented relatively north-south, which likely continues into the Makassar Strait waters towards and meets the North Sulawesi Trench. This fault is an active fault, as there is evidence of left-lateral strike-slip displacement annually at a rate of 34-58 mm/year [16]. Along the Palu-Koro fault line, there is an earthquake risk with a Modified Mercalli Intensity (MMI) level X scale according to the United States Geology Society (USGS) [14],[17].The phenomenon of liquefaction can be simply defined as a change in solid material, in this case in the form of sediment deposits or sedimentary soil, which due to an earthquake, the material seems to change its character like a liquid [18], [19]. More specifically, this event is called flow liquefaction [20], [21]. In general, liquefaction occurs in earthquake-prone areas, shallow groundwater levels and poorly consolidated soil. The main attributes used in the intrinsic assessment of groundwater vulnerability consist of: recharge, soil conditions, and aquifer - non-aquifer characteristics [22], [23], [24]. Secondary attributes consist of: topography, the relationship of surface water to groundwater, and aquifer units. All of these attributes are inseparable from the hydrogeological and hydromorphological conditions of groundwater.

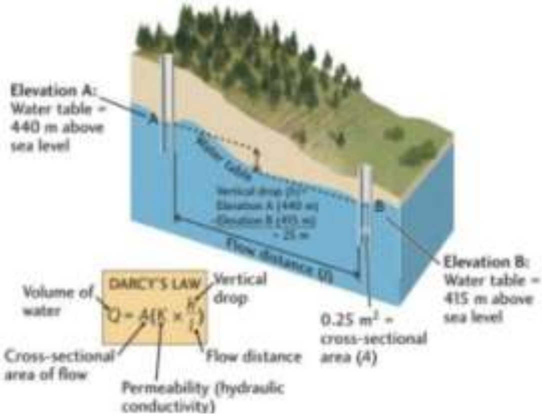

Figure 2: Groundwater Flow Model (Phreatic Level)

Determining the lateral and vertical distribution of aquifers and non-aquifers indicates the configuration of the aquifer system [17]. Groundwater studies cover a wide range of topics, including aquifer type, aquifer parameters that indicate aquifer characteristics, and their utilization and quality [18]. Geological information includes geological cross-sections, drilling and well logs, combined with hydrogeological information to identify the hydrostratigraphic units of the groundwater basin [15], [16], [17]. Geological cross-sections can reveal geological formations, stratigraphic units, piezometric planes, water chemistry, and formation correlations from drilling logs from several wells [9], [20].The geoelectric method is a method that studies the electrical properties within the earth and how to detect them on the earth's surface with the help of current injection into the earth. The main purpose of the geoelectric method is to find the resistivity value of a rock, in addition it can also be used to find other electrical properties such as induction fields and self-potential. The Wenner configuration is one of the configurations in geophysical exploration with an arrangement of electrodes located in a line symmetrical to the center point. The Wenner electrode configuration has good vertical resolution, high sensitivity to lateral changes but weak against current penetration towards the depth. The arrangement of the Wenner configuration electrodes can be seen in Figure 3 below:

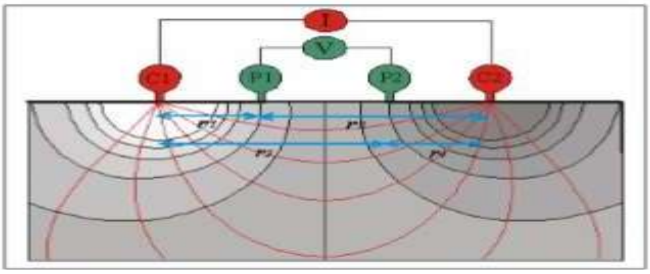

Figure 3: Wenner Configuration Electrode Arrangement (Loke & Barker, 1996)

II. Result And Discussion

This research was conducted in the Balaroa liquefaction area in Palu City, Central Sulawesi Province. Conditions in the Balaroa liquefaction area can be seen in Figure 5 below.Data collection techniques in this study employed survey and observation methods for primary and secondary data. Primary data included geoelectrical data collection and hydrogeological data collection from 25 groundwater wells. Secondary data used in this study included handbore data collection (one sample per line), JICA NSPT data, geological maps, topographic maps, and geomorphological and hydrogeological conditions of the study area before the disaster. The data analysis methods were as follows: (1). The hydrogeological complex and setting (HCS) method was used to determine the phreatic level before the liquefaction disaster, and (2). Geoelectrical data analysis using a Wenner electrode array using the RES2DINV program for aquifer hydrostratigraphy.

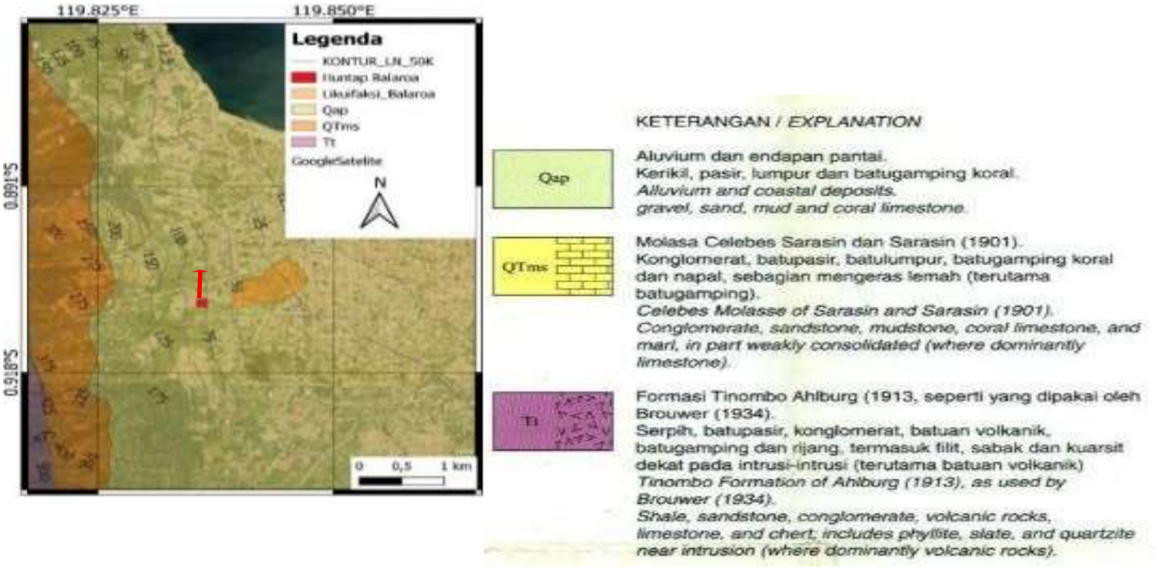

Figure 4: Geology of the Balaroa Liquefaction Area

2.1 Hydrogeological characteristics of the Balaroa area before the liquefaction disaster

Hydrostratigraphically, the Palu CAT is composed of 4 types, including (1) Unconfined Aquifer which is Alluvium and Beach Sediment (Qa) consisting of gravel, sand, mud, and coral limestone; (2) Aquitard composed of part of the Celebes Sarasin and Sarasin Molasses (QTms) consisting of conglomerate, mudstone, and marl; (3) Semi-confined aquifer in the Palu CAT composed of part of the Celebes Sarasin and Sarasin Molasses (QTms); and (4) Aquitard and bedrock with formations consisting of Granite and Granodiorite intrusive rocks (Tmpi), the Tinombo Formation (Tts), the Metamorphic Rock Complex (Km), and the Latimojong Formation (Kls).The results of pre-liquefaction disaster measurements, the distribution of phreatic surface depth in CAT Palu, ranged from moderate (2.5 – 7.0 meters dpt) – shallow (<2.5 meters dpt). The shallowest phreatic surface distribution (1.38 meters dpt) was in West Palu District (Balaroa) while the moderate phreatic surface (2.70 meters dpt) was only found in Gumbasa District.For details, please see the Figure 5.

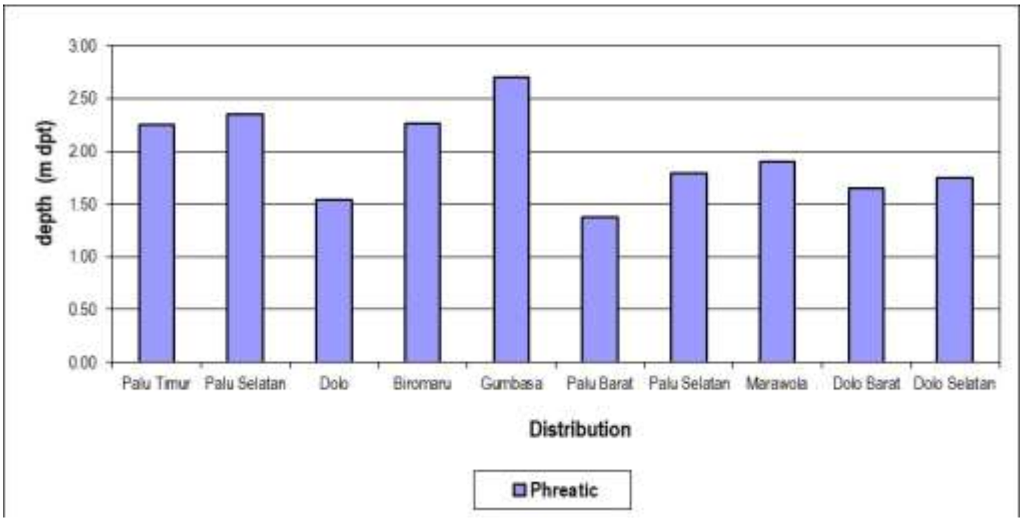

Figure 5: Graph of Phreatic Surface Depth Distribution at CAT Palu

This aquifer system is a potential primary aquifer, composed of coarse sand, fine sand, and clay. It is dominated by an unconfined aquifer with a thickness of >83.24 m. Geomorphologically, it covers almost the entire Palu CAT area. In the Balaroa area, groundwater flows continuously from the west (the slope bend of the structural hills of Mount Gawalise) toward the alluvial plains along the Palu River.

2.2 Hydrogeology and liquefaction prediction based on geoelectric measurement analysis

Geoelectric measurements in the Balaroa liquefaction area were conducted using one line of data collection. The Balaroa Line 1 Geoelectric Measurement point is located at latitude 816047.13 South and longitude 9899539.62 East. There are 21 electrodes with a spacing of 10 meters, for a total line length of 210 meters. The number of stakes, electrode spacing, and position of each stake are shown in Table 1 below.

Table 1: Number of electrodes, electrode spacing and position of each electrode marker line 1 Balaroa

Point	Distance (m)	Line 1		
		Latitude (m)	Longitude (m)	Elevation (m)
0	0	815956,82	9899482,79	59
1	10	815964,83	9899488,98	59
2	20	815972,52	9899494,09	59
3	30	815980,77	9899099,53	59
4	40	815988,85	9899504,84	58
5	50	815997,01	9899510,03	57
6	60	816005,34	9899514,93	56
7	70	816014,01	9899519,66	54
8	80	816022,13	9899524,52	52
9	90	816030,20	9899524,74	48
10	100	816038,86	9899535,02	47
11	110	816047,13	9899539,62	47
12	120	816055,68	9899544,74	46
13	130	816063,34	9899549,68	45
14	140	816072,09	9899553,90	45
15	150	816080,60	9899558,03	44
16	160	816089,31	9899563,52	44
17	170	816097,04	9899568,59	43
18	180	816105,04	9899574,04	43
19	190	816113,72	9899579,96	43
20	200	816121,02	9899584,93	42
21	210	816124,71	9899590,85	42

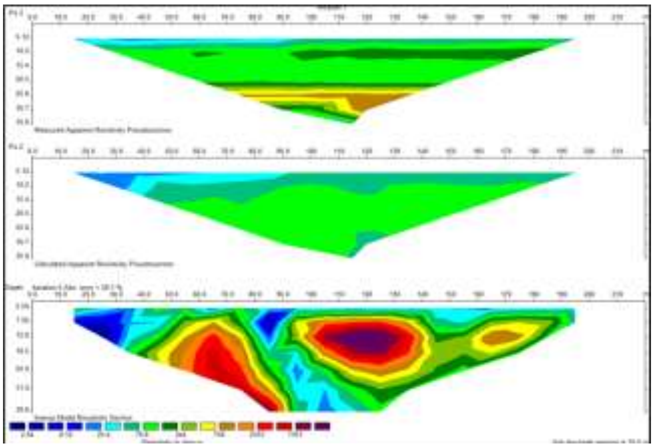

Figure 7: Resistivity cross-section of geoelectric data modeling on line 1 Balaroa

In general, the resistivity cross-section results from geoelectric measurements at the Balaroa Line 1 location can be interpreted based on the rock layers and geological conditions as follows:
a. The measurement span is 200 meters long with a penetration depth of 40 meters. Resistivity values at the Line 1 location range from 2 Ωm to 8000 Ωm.
b. Generally, subsurface resistivity is divided into four sections

Table 2: Resistivity and lithology values of line 1 Balaroa

No	Resistivity Value (Ωm)	Depth (m)	Lithology
1.	2 - 30	Evenly distributed on the measuring cross section	The surface soil layer of Alluvium is saturated with water
2.	30 - 100	Evenly distributed on the measuring cross section	Weathered layers of conglomerate rocks from the Molasa of Sulawesi
3.	100 - 500	Evenly distributed on the measuring cross section	weathering granite
4.	500 - 8000	Located at a depth of 8 meters	Granite Chunks

The cross-section of the Balaroa line 1 track reveals a picture of the subsurface lithology. The surface soil layer (alluvium) is saturated with water. These results identify a liquefaction zone at a depth of ≤ 18.5 meters. The 2D geoelectric results in this area show a low resistivity value of ≤ 2 Ωm, which identifies this as a saturated zone and a productive aquifer.

III. Conclusion

1. Pre-disaster liquefaction measurements show that the phreatic surface depth distribution at the Palu CAT ranges from moderate (2.5–7.0 meters) to shallow (<2.5 meters). The shallowest phreatic surface distribution (1.38 meters) is in West Palu District (Balaroa).
2. The Balaroa Line 1 cross-section shows the subsurface lithology. The surface soil layer (alluvium) is saturated with water. These results identify a liquefaction zone at a depth of ≤ 18.5 meters. It was observed that the rerun column bottom stream temperature has greater effect on the linear alkylbenzene yield than the temperature variation of the top stream. At higher temperature of both streams , lower percentage yield of average wt. % of linear alkylbenzene was obtained with that of the top stream being the lowest at 87.5% as against 93.3% for the bottom stream. The highest linear alkylbenzene yield of 99.4%was recorded at bottom stream temperature of 280^{o}C and pressure of 115Kpa.

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