Study of the Depth of Groundwater Layers Using the Ordinary Block Kriging Method and It's Effect on the Occurrence of Liquefaction in the Petobo Area of South Palu, Indonesia

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Abstract. Petobo as the location of the research area is part of the city of Palu, namely in the South Palu sub-district area. The topographic profile of this region is a flat area, most of which is used as rice fields and some have developed into residential areas. In Palu city planning. Before the earthquake occurred on September 28 2018, this area would be developed into the future development of the city of Palu. After the earthquake and liquefaction, the Central government designated this area as a red category area which indicates that it is unsafe for settlement due to liquefaction that occurred during the earthquake on September 28 2018. We want to use the Block Kriging method together with the Geophysical method. to determine the composition of the subsurface soil that caused liquefaction in the 2018 earthquake. The Ordinary Kriging method found deep groundwater at a depth of 59.70 m, while the Geoelectric method after the earthquake found deep groundwater at a depth of 66.67 m, giving almost the same results. The depth of groundwater near the surface is around 14.7 m, while the Geoelectric Method before the earthquake and liquefaction found 15 m. Petobo's position, which is lower than Biromaru and the Gumbasa Dam water channel, is one of the causes of liquefaction.

Keywords: Liquefaction, Block Kriging, Geoelectric Method.

1. INTRODUCTION

The Petobo area in South Palu subdistrict, Palu City, consists of rice fields and residential zones on flat terrain. Although urban planning aims to develop this area, it has been designated a red zone due to the liquefaction caused by the earthquake on September 28, 2018. Liquefaction occurs when an earthquake shakes the soil, causing sand and groundwater to mix, turning the ground into mud. This phenomenon, observed during the

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Palu liquefaction, highlights the need to study the groundwater depth and subsurface rock composition in Petobo [1]. The geological structure of the Palu Valley includes Celebes Molasse sediments like clay, sand, and gravel, making it challenging to find groundwater near the surface in highland areas like Tondo, but not in lowland areas like Petobo [2]. This study uses the geoelectric method and Ordinary Block Kriging, which employs a Semivariogram approach to estimate unsampled physical parameters [3]. Nur'eni et al. (2019) successfully applied this approach to find groundwater in Tondo Mantikulere, Palu [4], and Laksana (2017) highlights its use in estimating groundwater and oil content. Semivariogram calculations help determine parameters like sill, range, and nugget, which are crucial for accurate Block Ordinary Kriging [5]. The study aims to find groundwater and its constituent rocks in Petobo for more accurate results, assess the depth map of groundwater affected by liquefaction, and create a contour map of groundwater sources in South Palu district.

2. MATERIAL AND METHODS

2.1 Spacial Data

Data collection at the research location using statistical methods produces spatial data presented as geographic positions, locations, and relationships using coordinate points and areas. In Euclidean space, let $s \subset R^d$ be the location and $Z(s)$ the backup data in the well. The second-order stationarity of the spatial process $\{Z(s) : s \in D\}$ is be the satisfied [6] if: $E[Z(s)] = m, \forall s \in D$ (1), and the covariance function between two points s and $s + h$ is independent of s's location and is dependent on the vector separating h: $Cov\{Z(s), Z(s+h)\} = E[Z(s)\, Z(s+h)] - m = C(h)$ (2). The semivariogram value $\gamma(h)$ describes the spatial correlation: $\gamma(h) = \frac{1}{2}E[Z(s) - Z(s+h)]^2$ (6) The experimental variogram is formulated as: $2\gamma(h) = \frac{1}{N(h)}\sum[Z(s_i) - Z(s_i + h)]^2$ (7), where $N(h)$ is the number of data pairs in the lag distance h.

2.2 Experimental Semivariogram, Basic Theory of Geoelectrical Method Morphology of Palu Valley, Liquefaction, and Basic Theory of Earthquake

The experimental semivariogram, calculated ascalculated as $2\gamma(h) = \frac{1}{N(h)}\sum[Z(s_i) - Z(s_i + h)]^2$, measures spatial correlation between random variables $Z(s)$ *and* $Z(s+h)$. Key parameters include the nugget effect, sill, and range, with models like spherical, exponential, and Gaussian aiding in definition. Ordinary Kriging estimates values at unsampled locations, while Block Kriging extends to blocks of data, with model accuracy assessed using Mean Square Error (MSE). A geoelectrical survey measures subsurface rock resistivity to identify rock types, groundwater potential, and sediment thickness. In Petobo, these surveys assessed rock layers and groundwater, correlated with geological and hydrogeological data, to understand their relationship with the September 28, 2018, earthquake-induced liquefaction. The Palu Valley's morphology is divided into valley, upland, and hilly units, with liquefaction significantly damaging South Palu's buildings. Plate tectonics theory, explaining tectonic plate interactions, accounts for geological features like mountains and earthquakes, with the Palu-Koro fault and related geological structures characterizing the region's geoelectrical structure.

2.3 Data Collection and Analysis

The study used secondary data, including bore well data, location coordinates, and sea level heights, along with primary geoelectric data from Petobo, South Palu, Central Sulawesi. Data analysis involved the Ordinary Block Kriging method and R 3.5.2 software, encompassing multiple stages: data collection, geoelectric data processing, geoelectrical modeling, groundwater field data description, determining experimental semivariogram values to obtain Sill, Range, and Nugget parameters, comparing these values to the semivariogram model for best fit, performing Ordinary Block Kriging estimation, and mapping groundwater depth to conclude and discuss the results.

3 RESULTS AND DISCUSSION

3.1 Experimental Semivariogram, Structural Analysis and Ordinary Block Kriging Estimation

The experimental semivariogram values, based on distances between observation points, indicated spatial correlations with thirteen experimental values used to create a model. Structural analysis compared the Mean Square Error (MSE) between experimental and theoretical semivariograms, selecting a theoretical model with parameters: Sill = 1,190, Range = 6,000, and Nugget = 5,987. The spherical model was chosen for Ordinary Block Kriging estimation, using a 100x100 grid size, and generating a contour map highlighting optimal groundwater extraction areas. Contour maps from Ordinary Block Kriging and geoelectrical methods identified layers of sandy clay, sandy gravel, and boulders, with the sandy gravel layer acting as the primary aquifer. Groundwater seepage from higher irrigation channels contributed to liquefaction during the 2018 earthquake in Petobo, South Palu. Accurate subsurface characterization is crucial for mitigating such natural disasters.

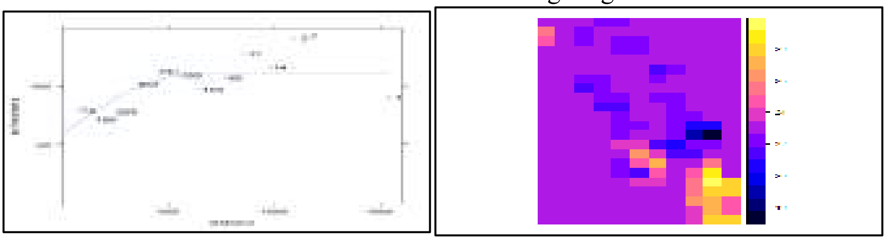

Fig. 1. Semivariogram and Plot of Ordinary Block Kriging Estimation

3.3 Results of Investigation using Geoelectrical Method and Liquefaction in Petobo, South Palu

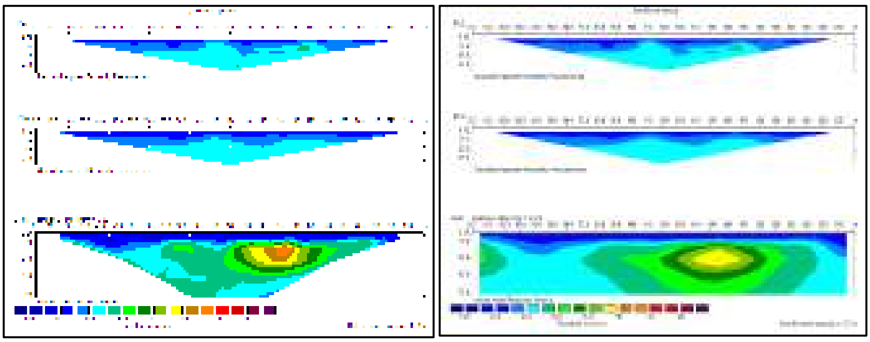

Fig 2. Subsurface cross-section & Cross-section of Line 2 using Wenner configuration

In the geoelectric line 01 Wenner 2D configuration, a dark blue layer with a resistivity value of less than 30 Ohmmeter is identified as sandy clay dominant on the surface, while a light blue to yellow layer with a resistivity value between 30 Ohmm and 105 Ohmm is identified as sandy gravel, found above 4 meters below the surface and acting as an aquifer. Community information suggests that the higher position of the Gumbasa irrigation channel compared to Petobo likely caused water seepage, leading to liquefaction during the earthquake in Petobo. Liquefaction, which occurs in water-saturated soil when pore water pressure exceeds the soil's friction strength due to a strong earthquake, affected thousands of houses over hundreds of hectares. Research indicates that soils susceptible to liquefaction typically consist of sand or sand-sized materials. The Ordinary Block Kriging method found shallow groundwater at 59.6 meters with an MSE of 4.11 percent and at 14.6 meters, consistent with the Geoelectric method, which found shallow groundwater at 15 meters and deep groundwater at 66.67 meters. Liquefied materials are usually around 20 meters deep but can be deeper depending on soil distribution, and liquefaction only occurs below the groundwater level.

4 CONCLUSION

The study concluded that the Ordinary Block Kriging method identified shallow groundwater at 14.6 m and a deep reservoir at 59.70 m, while the geoelectric method found shallow groundwater at 15 m and deep groundwater at 66.67 m, indicating practical agreement between the two methods. The dominance of sandy loam layers and Petobo's lower position relative to the Gumbasa Dam's water flow are suspected factors causing liquefaction during the September 28, 2018 earthquake.

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