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Soil Porosity Conditions in Flood-Prone Areas of the Prosperous Swamp of Bengkulu City Based on Geoelectrical Measurement

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Abstract

Surface porosity conditions in part of flood-prone areas at Rawa Makmur Village have been mapped from the surface to a depth of 30 meters. The aims of this research are to identify the infiltration of soil which is described by variations in resistivity and rock porosity values. It is obtained from the 1D geoelectric method (line 120 meters), using Vertical Electrical Sounding and as many as 10 measurement points. Data processing uses progress software and is interpreted in the form of a spatial map of the distribution of resistivity and porosity values. According to analysis, it is explained that Rawa Makmur area has low porosity and resistivity values. Starting from a depth of 5 meters, the porosity conditions in the observation point area were in very bad conditions. The infiltration process is very slow, causing the accumulation of a large amount of water mass and a fairly high pool of water. The resistivity value of this area has low resistivity and rock porosity values. It also showed that the water flowing in this area was difficult to infiltrate, so it caused the Rawa Makmur area to become flooded when it rained.

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1. INTRODUCTION

Rawa Makmur Village, especially in locations near rivers, is one of the areas that is most often affected by flooding, especially when high-intensity rainfall occurs. High rainfall causes the volume of water to increase while the absorption capacity of the soil for water decreases, so this causes flooding at several points around Rawa Makmur. The conditions that occur in the Rawa Makmur area can be seen in Figure 1.

Figure 1. Floods that occurred in the Rawa Makmur sub-district in 2019

Infiltration rates in land use vary depending on the type of land use and several factors that affect the physical properties of the soil, including soil texture, organic matter, density, mass, porosity, aggregate stability and moisture content [1]. However, to ascertain the infiltration rate at several locations in Rawa Makmur, research is needed by mapping these parameters based on geoelectric measurements of resistivity. Based on these conditions, the formulation of the problem in this study was to examine the effect of soil physical properties on the ability of the soil to absorb water with the parameters of soil physical properties (Porosity) in the Rawa Makmur sub-district. The purpose of this study was to be able to map the ability of the soil to absorb water in the Rawa Makmur sub-district.

2. MATERIALS AND METHOD

Geoelectrical data collection was carried out in the Rawa Makmur sub-district, Muara Bangkahulu District, Bengkulu City. With a total of 10 measurement points, using the 1D geoelectric method with a stretch length of 120 m. 1D geoelectric measurements with the Schlumberger configuration. Then the data obtained in the field was processed using progress software, Voxler, and mapped using ArcGis software. The distribution of research point locations can be seen in Figure 2.

Interpretation and analysis of the results are based on the results of mapping the rho values for each depth. This interpretation provides information on lithological conditions and water content in a rock. In addition, another interpretation is the distribution map of porosity conditions in the observation area. This map describes the condition of rock porosity related to soil absorption of water. The greater the porosity, the better the rock absorbs water, and the smaller it is, the lower the absorption capacity.

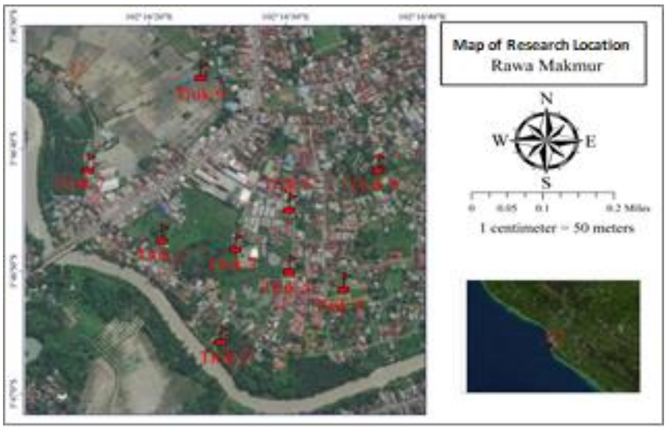

Figure 2. Distribution of VES measurement points in flood-prone areas in Rawa Makmur Village

2.1. Basic Principles of the Resistivity Geoelectrical Method

Geoelectric is a geophysical method that utilizes the nature of the earth as a survey parameter. Broadly speaking, geophysical methods are of two types, namely, passive geoelectrical methods and active geoelectrical methods [2,3]. This geophysical method generally assumes the earth is one layer so that the parameters obtained are pseudo parameters [4,5].

The basic concept of the resistivity method is Ohm's law. Where R is the resistance of the material, I is the magnitude of the current, and V is the magnitude of the voltage. Ohm's law states that the potential or voltage between the ends of a conductor is equal to the product of the resistance and the current. It is assumed that R is constant

$$V = I \, . \, R \tag{1}$$

where R is the resistance of the material (ohms), I is the magnitude of the current (amperes), and V is the magnitude of the voltage (volts). Ohm's law states that the potential or voltage between the ends of a conductor is the product of the resistance and the current. It is assumed that R is constant [6]. In the resistivity method, the measurement parameter is the resistivity of the rock inside the earth (see Table 1 and Table 2). Resistivity is a quantity that indicates the degree of resistance of an object against an electric current. Materials that have a large resistivity value mean that it is more difficult for an electric current to pass [7].

Table 1. Variation of rock resistivities [8]

Type of Rock/Soil/Water	Resistivity (Ohm)
Clay	1-100
Silt	10-200
Marls	3-70
Quartz	$10\text{-}2\text{x}10^{8}$
Sandstone	50-500
Limestone	100-500
Lava	$100\text{-}5\text{x}10^{4}$
Groundwater	0,5-300
Seawater	0,2
Breccia	75-200
Andesite	100-200
Vulcanic Tuff	20-100
Conglomerate	$2\text{x}10^{3}\text{-}10^{4}$

Table 2. Resistivity values of various soil types [9] in [10]

Type of Rocks/Soil	Resistivity (Ohm)
Clay soil, wet loamy	1,5-3,0
Wet silt and silt soil is soft	3-15
Silt, sandy soil	15-150
Sand gravel with a layer of silt	300
Bedrock contains dry soil	300-2400
Bedrock is not weathered	>2400

According to [11] there are several factors that affect the value of resistivity in rocks, namely the type of material, water content, rock porosity and chemical properties.

2.2. Porosity

Porosity is one of the factors that determine the resistivity value of a rock. The difference in porosity is caused by differences in soil texture, namely the relative comparison of various particle sizes (separations/fractions) in the soil [12]. Soil texture classes are classified based on the ratio of the number of grains of sand, silt and clay. Soil with a clay texture has a large surface area so it has the ability to hold water and provide high nutrients [13].

The soil pores are usually occupied by air for coarse pores, while the small pores will be occupied by water. To determine the number and nature of pores, it is necessary to measure the pore size in the pore composition of the soil. Porosity is the ratio between the volume of the pore space and the total volume of the soil expressed in percent. To determine the number and nature of pores, it is necessary to measure the pore size in the soil pore arrangement [14].

Porosity is the ratio between the volume of the pore space to the total volume of the soil expressed in percent (%). Porosity is closely related to the level of soil density, the denser the soil, the smaller the soil porosity and vice versa [15]. Soil porosity classes are shown in Table 3.

Table 3. Porosity of some reservoir [16]

Porosity (%)	Quality
0 – 5	Ignored
5 – 10	Bad
10 – 15	Enough
15 – 20	Good
20 – 25	Very good
>25	Excelent

The porosity of the subsurface material or rock can affect the resistivity value. Porosity can be calculated using equation 2 of Archie's Law [2]. The suggested values for the constants α and m are used in the Archie formula when the lithology of the rock is known [6].

$$\rho_f = \alpha\phi^{-m}S^{-2}\rho_w \tag{2}$$

To find out the value of porosity, (equation 2) can be written as follows:

$$\phi^m = \alpha \, S^{-2} \, \rho_w \, \rho_f^{-1} \tag{3}$$

where:

ρ_f = formation resistivity (Ω.m)
ρ_w = Pore resistivity - water (Ω.m)
α = Tortuosity
m = Cementation factor
ϕ = Porosity (%)

S = fraction of pore volume filled with groundwater (saturation)

3. RESULTS AND DISCUSSION

The phenomenon of waterlogging in Rawa Makmur generally occurs due to high rainfall intensity, overflow of river water and supported by subsurface rock lithology conditions which have reduced water absorption or infiltration capacity. This lithology condition is then described by resistivity and porosity values from geoelectrical measurements. The 1D interpretation of the resistivity values at observation point 4 is shown in Figure 3.

Figure 3 shows that the resistivity value varies for each depth, namely in the range of 4.40 ohm.m to 33.71 ohm.m. This 2D interpretation forms the basis for constructing the interpolation of 10 VES measurement points to become a 3D interpretation (Figure 4 and Figure 5). This value depends on the depth of measurement and the type of rock that makes it up. This value is inversely proportional to the porosity of the rock, where the higher the resistivity value, the lower the porosity value.

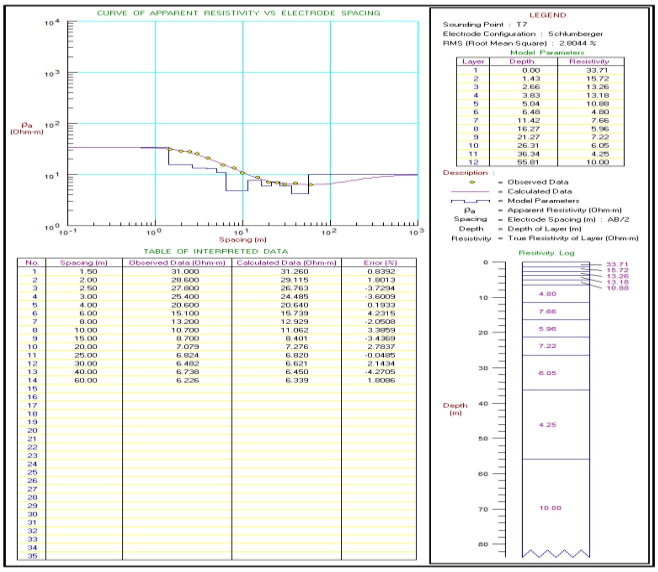

Figure 3. The research flowchart

In Figure 4, it can be seen that the resistivity value at a depth of 1-5 meters is very high, which means that at that depth it indicates a dry area so that it can absorb water easily, but actually a depth of 1-5 meters is indicated as dry heaped clay, so that the absorbency soil resistance to water only to a depth of 5 meters but when the depth is 0-30 meters the resistivity value decreases. This interpretation assumes that areas with low resistivity values are difficult to absorb water because at that depth there is water that is trapped in rock pores so that the ability of the soil to absorb water is reduced, this causes a pool of water volume when it rains.

In Figure 5, it can be seen that the porosity value of the constituent rocks in Rawa Makmur is different at each depth, at a depth of 1-5 meters the rock porosity value is very low (blue in color) making it difficult to absorb water. but at a depth of 5 meters to the East the rock porosity value is high and this indicates that the area can absorb water at a depth of 5 m, then for a depth of 10 - 25 meters it is seen that the porosity value increases in the Northwest direction, this indicates that the area is Northwest of Rawa Makmur Village has a high porosity value at a depth of 10-25 meters but when the depth increases, the porosity value returns to be small and this indicates that the Rawa Makmur area is indeed in a state of rock that is difficult to absorb water coupled with the absence of good irrigation channels, so when the river water overflows, it is difficult for the rocks in the Rawa Makmur area to absorb water.

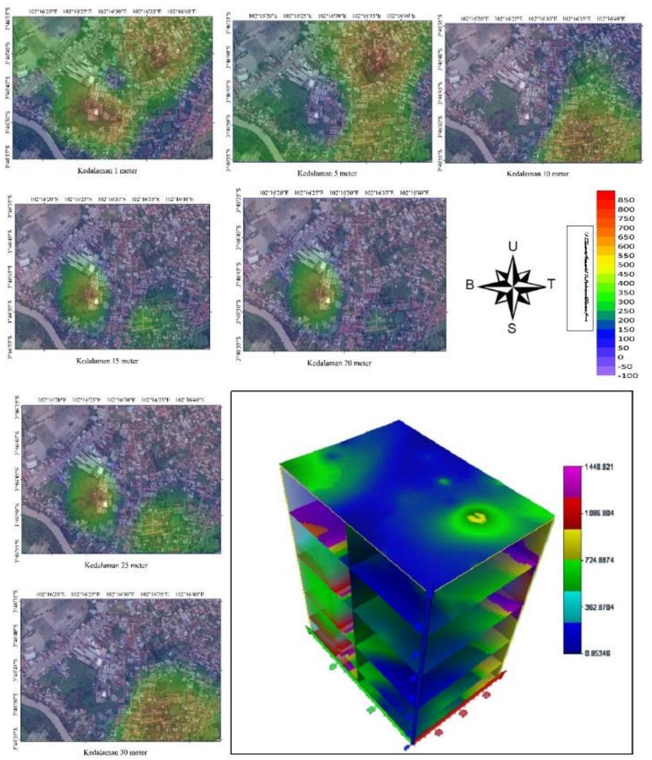

Figure 4. Distribution map of the resistivity value of the observation area from the surface from a depth of 0 m (surface) to a depth of 30 meters

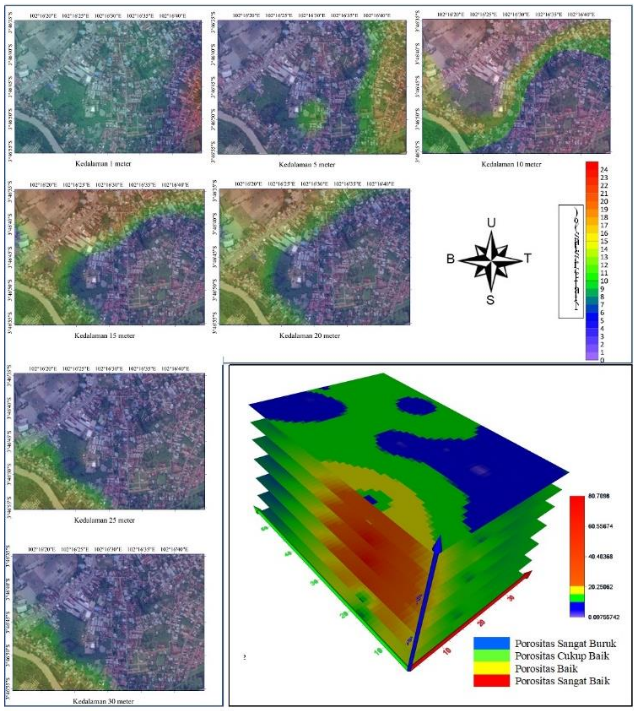

Figure 5. Distribution map of porosity values to depth from the surface to a depth of 30 meters

Based on the interpretation in Figure 4 and Figure 5, it can be said that at a depth of 0-5 meters the resistivity value is higher than at a depth of 5-30 meters, so the porosity of the rock at a depth of 0-5 meters is very low, this causes more water to flow at that depth. difficult to be absorbed by the rock below. This condition causes when it rains, the rocks in the Rawa Makmur Village area are difficult to absorb water. This statement is supported by the rock porosity distribution map in Figure 5.

In addition, it can also be seen that the porosity and resistivity values of the rocks in the Rawa Makmur area are correlated with each other and are supported by flood events that have occurred in this area. river overflow, but to reduce the impact of flooding, this area can make deep irrigation canals even though the conditions in the field in the Rawa Makmur area are slightly lower than the river flow.

4. CONCLUSION

The conditions in the Rawa Makmur area based on the resistivity value of this area have low rock resistivity and porosity values. From the data measured and interpreted, it shows that the water flowing in this area is difficult to infiltrate into the surrounding rock, which causes the Rawa Makmur area to become prone to flooding when it rains.

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