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Research Article

Coastal Hydrogeological Model in the Iron Ore Prospect Area of Widarapayung Coastal, Cilacap Regency Based on 2D-Resistivity Data

Sehah [1,a], Sukmaji Anom Raharjo [1,b], and Abdullah Nur Aziz [1,c]

[1] Department of Physics, Faculty of Mathematics and Natural Sciences, Jenderal Soedirman University
Jalan Dr. Suparno No. 61 Karangwangkal, Purwokerto 53123, Indonesia

e-mail: [a] sehah.geophysics@gmail.com, [b] raharjoajie@gmail.com, and [c] abdnuraziz@gmail.com

Abstract

The coastal hydrogeological model of iron ore prospect area in Widarapayung coastal, Cilacap Regency, has been designed and performed based on the 2D-resistivity data. The background of this research is potentiality of iron sand in this area and its prospect to be mined. Mining activities in large-scale may lead into surface decreasing, triggering damage to the aquifer, abrasion, and saltwater intrusion in the coastal area. The acquisition of 2D-resistivity data has been performed on five trajectories including of WP-01 up to WP-05. Based on the modeling results, it can be concluded that the sub-surface rocks resistivity profile consists of WP-01 with the values of 1.93-114.00 Ωm; WP-02 with the values of 3.67-121.00 Ωm; WP-03 with the values of 3.86-78.40 Ωm; WP-04 with the values of 1.79-100.00 Ωm; and WP-05 with the values of 2.61-86.20 Ωm. After interpretation, it is found that the hydrogeological profile of sub-surface rocks consists of sand inserted with gravels (topsoil); sand containing iron ore granules inserted with silt (topsoil and shallow aquifer); clayey sand (semi-aquifer layer); sandy clay (semi-impermeable layer); and sand (deep aquifer which is intruded by salt water). Based on the analysis, the sand containing iron ore is part of the shallow aquifer, so the mining activities of iron sand is potential to damage and reduce aquifer function in storing and flowing the groundwater in the research area.
Keywords: *hydrogeology, resistivity method, sub-surface rocks, iron ore, Widarapayung coastal area*

Model Hidrogeologi Pantai di Kawasan Prospek Bijih Besi Pesisir Widarapayung Kabupaten Cilacap Berdasarkan Data Resistivitas 2D

Abstrak

Model hidrogeologi pantai di kawasan prospek bijih besi Pesisir Widarapayung Kabupaten Cilacap telah dirancang berdasarkan data resistivitas 2D. Latar belakang penelitian ini adalah adanya potensi pasir besi yang prospek ditambang. Penambangan dalam skala besar dapat mengakibatkan penurunan permukaan pantai, sehingga memicu kerusakan akuifer, abrasi, dan intrusi. Akuisisi data resistivitas 2D dilakukan di atas lima lintasan yang terdiri atas WP-01 hingga WP-05. Berdasarkan hasil pemodelan, diperoleh profil 2D resistivitas batuan bawah permukaan yang terdiri atas lintasan WP-01 dengan nilai 1,93 – 114,00 Ωm; WP-02 dengan nilai 3,67 – 121,00 Ωm; WP-03 dengan nilai 3,86 – 78,40 Ωm; WP-04 dengan nilai 1,79 – 100,00 Ωm; dan WP-05 dengan nilai 2,61 – 86,20 Ωm. Setelah dilakukan interpretasi, diperoleh profil hidrogeologi bawah permukaan 2D yang terdiri atas pasir yang bersisipan dengan kerikil (top soil); pasir yang mengandung butiran bijih besi berselingan dengan lanau (top soil *dan akuifer dangkal); pasir lempungan (lapisan semi akuifer); lempung pasiran (lapisan semi kedap); dan pasir (akuifer dalam terintrusi air asin). Berdasarkan hasil analisis, pasir yang mengandung bijih besi merupakan bagian dari akuifer pantai, sehingga penambangan pasir besi berpotensi merusak dan menurunkan fungsi akuifer dalam menyimpan dan mengalirkan air tanah di daerah penelitian.*

Kata Kunci: *hidrogeologi, metode resistivitas, batuan bawah permukaan, bijih besi, kawasan Pesisir Widarapayung*

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I. INTRODUCTION

Widarapayung Coast is an area in Cilacap Regency, Central Java, which has quite a lot of iron ore deposits. This area is located about 30 km distance in the eastern of Cilacap City. The characteristic of the iron ore in this area is that it has magnetic degree of 2.20% and an iron content of more than 53%. This coastal area which is suspected to contain iron ore, is stretching from Welahan Wetan village in Binangun to Jetis village in Nusawungu. To this day, the iron sand in this coastal area has not been officially mined [1].

Geologically, the rocks in the research area is composed of alluvium and coast deposits. Based on the results of the research by Sehah *et.al*. [2], the sub-surface object is interpreted as sand containing iron ore inserted with clay, silt, and gravels. The value of magnetic susceptibility of the object is estimated to be about 0.0093 in cgs unit. In addition, based on the results of research that has been conducted in the eastern research site, it is known that an aquifer exists in the alluvium [3], which serves to store and drain groundwater in the coastal area. Therefore, the mining activities of iron ore in large scale is feared to potentially damage the alluvium deposits; it might trigger abrasion and saltwater intrusion into the aquifer [4].

The coastal aquifer is freshwater source that is potentials in the research site, such as for drinking, cooking, bathing, etc. Currently, this area has been developed to be an agro-tourism area, in which requires lots of freshwater. Some vegetables and fruits such as eggplants, chili, spinach, melon, and watermelon have begun to be planted in this area. Those plants need freshwater as well. Saltwater intrusion may disrupt the growth of the plants that cannot be adaptable to saltwater, causing major catastrophe to the plants. Agricultural enterprises in this area may also suffer loss since the decreased supply of freshwater for the irrigation [5].

To know the physical characteristics of the coastal aquifers in the Widarapayung coastal area, a geoelectrical survey could be applied, of which resistivity method is one of the geoelectrical surveys that can be employed with the objective to obtain the sub-surface resistivity profile in the research area based on the 2D-resistivity data. This resistivity profile is interpreted based on the geological information to obtain the coastal hydrogeological profile for the area; therefore, the potentials of the decreased aquifer function and the saltwater intrusion into the coastal aquifer can be detected early. The resistivity method is believed as the most suitable method among all geophysical methods for delineation of hydrogeological profile because its principle is based on the value changes of sub-surface rocks resistivity [6,7].

This research objective is to obtain the 2D-hydrogeological profile of the sub-surface based on the modeling and interpretation of the sub-surface rocks resistivity data. The 2D-hydrogeological profile model can be used to evaluate the potentials of the decreasing aquifer function in the coastal area easily as the negative impact of the iron sand mining. The form of the decrease of the aquifer function is a decrease in the ability of aquifer materials to store and drain a number of groundwater in the coastal area.

The use of the resistivity method as a tool of geophysics for exploration is based on the electric current flow through the ground and rocks materials. The data collection in the survey can be performed by injecting direct current (DC) into the ground through two current electrodes, i.e. C_1 and C_2. The current will spread evenly to the ground and sub-surface rocks, as illustrated in Figure 1. The polarization in the rocks is measured by the voltage across two potential electrodes, i.e. P_1 and P_2. After current and voltage are measured directly, the apparent resistivity value of sub-surface rocks can be calculated by simple equation:

$$\rho_a = K \frac{\Delta V}{I} \qquad (1)$$

where ρ_a is the apparent resistivity, K is the geometrical factor, ΔV is the voltage and I is the current [8].

Based on Figure 1 [8], the geometrical factor is generally given by:

$$K = 2\pi \left[\left(\frac{1}{C_1P_1} - \frac{1}{P_1C_2} \right) - \left(\frac{1}{C_1P_2} - \frac{1}{P_2C_2} \right) \right] \qquad (2)$$

The K factor in the equation (2) will give a certain value for a given electrode spacing. For Wenner configuration, all inter-electrode spacing are equal to the constant value a. Thus, the geometrical factor can be written as follow:

$$K = 2\, \pi\, a \qquad (3)$$

In general, every type of sub-surface rocks has different resistivity value. The rock resistivity value depends on various variables such as density, water content, mineral, salt content, and porosity [9]. Hence, the resistivity of rocks is not single-valued but in interval [10]. Rocks with high salt content will be conductive so that the resistivity value is low. Therefore, the resistivity value of the aquifer which is intruded by saltwater may differ from the freshwater aquifer. The difference in value of resistivity can be used as a basic for objects modeling [11,12]. The results which is obtained from the modeling is the 2D-sub-surface rock resistivity profile. This 2D-resistivity profile is interpreted based on the geological data, so the information related with the hydrogeological profile of the research area can be obtained.

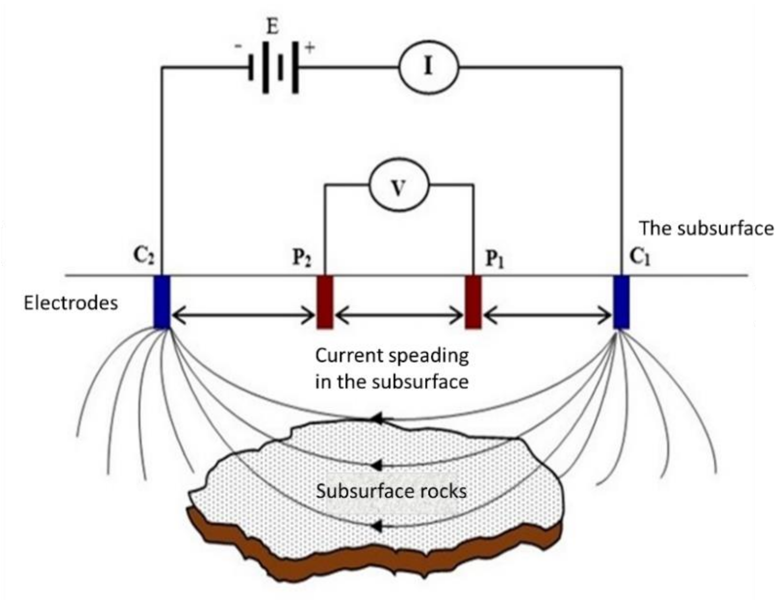

Figure 1. The scheme of 2D-resistivity data acquisition in the field

II. RESEARCH METHOD

The method used in this research is a survey. Data acquisition of 2D-resistivity using the Wenner configuration has been done in the Widarapayung Coastal, Cilacap Regency, Central Java (Figure 2). The processing, modeling, and interpretation of resistivity data were carried out at the Laboratory of Geophysics, Faculty of Mathematics and Natural Sciences (MIPA), Jenderal Soedirman University Purwokerto, Central Java, Indonesia. This research was completed within six months, from March to August 2018.

Figure 2. Research location (in the red box)

Tools and Materials

The required main equipment in this research included resistivitymeter NRD-300 type with supporting tools, global positioning system (GPS), handy talky (HT), geological map of Cilacap area, Google Map application, and other equipment.

Research Procedures

The research begun with the determination of data acquisition location in the research area. The acquisition of data related with resistivity was carried out by employing Wenner configuration, where all electrodes were located on the left of trajectory with equal spacing, i.e. a. Next, the electrical current (I), the voltage (V), and the spacing between electrodes were measured. Then, all electrodes were moved to the right in distance of a; i.e. C_1 was displaced to P_1, P_1 was displaced to P_2, and P_2 was displaced to C_2. After that, those values were measured again. The acquisition of resistivity data was done repeatedly until all of trajectory has been measured. In order to obtain the information related with the 2D-resistivity profile on the trajectory, measurement of resistivity data was conducted several times. In each measurement, spacing between those electrodes was always widened to be $2a$, $3a$, $4a$, $5a$, $6a$ and so on, as shown in Figure 3. However, the distance of electrodes displacement to the right of trajectory was kept constant, i.e. a [13].

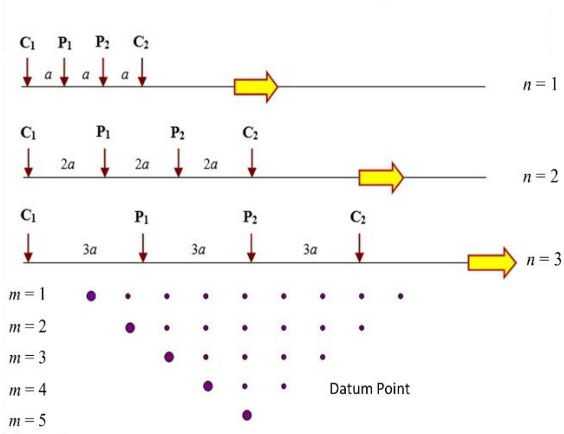

Figure 3. Sketch of resistivity data acquisition technique using Wenner configuration

III. RESULTS AND DISCUSSION

Results

The 2D-resistivity data acquisition were carried out on five trajectories in the research area. Those trajectories were placed in the iron ore prospect area according to the magnetic survey results by Sehah *et.al*. [2]. The length of each trajectory was 200 meters and their position is shown in Figure 4. The data which were obtained in the field for each trajectory were in the form of values consisting of electrical current, voltage, spacing between electrodes, and electrode displacement spacing. The data measurement was performed 63 times for each trajectory. Based on the acquired data, the geometrical factor (K_{Wen}) and the apparent resistivity (ρ_a) values for each measurement could be calculated. The datum point for each measurement can be determined based on spacing between electrodes and electrodes displacement spacing used in the research.

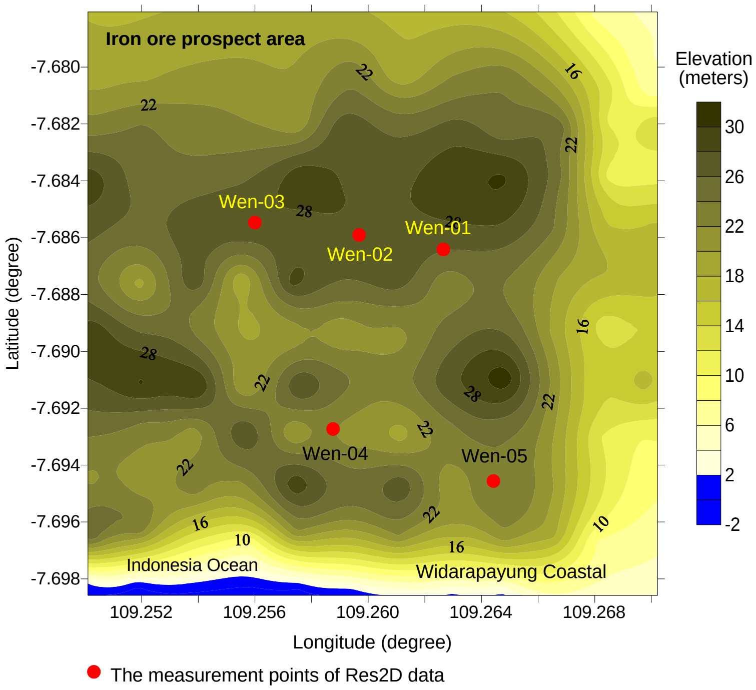

Figure 4. Location of the measurement trajectories on the topographic map of Widarapayung coastal area, Cilacap Regency

The apparent resistivity data (ρ_a) that were acquired from the calculation were modeled using Res2Dinv 3.54 to obtain the true resistivity data (ρ_T) in the form of 2D-sub-surface resistivity profile. The sub-surface resistivity profile resulted from the modeling for WP-01 to WP-05 trajectories is shown in Figure 5 to Figure 9. The modeling results show that the resistivity value trend of subsurface rock is decreasing downward. The modeling maximum depth is about 31.9 meters from topographic surface. Interpretation to the 2D-resistivity profile has resulted in types of rocks, as can be seen in **Table 1** until **Table 5**. This interpretation is based on the geological information of the research area [14]. The interpretation results was then designed using Res2Dinv 3.54 to gain the coastal hydrogeological profile, including the types of sub-surface rocks and physical characteristics of its aquifer [15]. This is very important as it is useful to evaluate the potentials of freshwater sources in the research area.

Based on the results, the interpretation indicates that the sand containing iron ore inserted by silt are dominant in the research area. In addition, this sand also acts as a groundwater aquifer, which is a potential freshwater source in the research area. If iron ore mining is carried out on a large scale in the research area, it may affect the surroundings, such as the decreasing coastal surface as the sand and other materials are lost due to the mining activities. It foreshadows a decrease in the aquifer's function to store and drain the groundwater in the area. In addition, the iron sand mining activities are believed to accelerate the abrasion in the research area due to the decrease in the coastal surface, as it has happened in the Bunton coastal area, District of Adipala, Cilacap Regency, Central Java [16]. Moreover, the mining activities also damage the coastal forests and other vegetation which are significantly useful as the buffer from sea winds and tsunami waves.

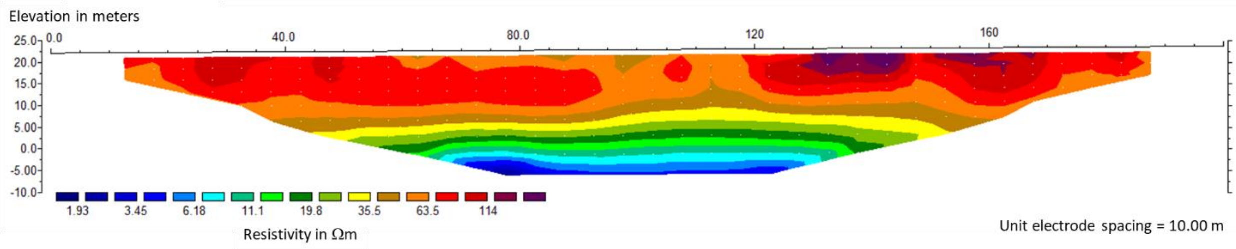

Figure 5. The 2D-resistivity profile contour obtained from inversion modeling on WP-01 trajectory

Table 1. The results of interpretation of the 2D-resistivity profiles on the WP-01 trajectory

No.	**Resistivity (Ωm)**	**Interpretation of Hydrogeology**	
		Lithology	**Hydrology**
1	< 3.46	Sand	The deep aquifer (intruded by saltwater)
2	3.46 – 11.1	Sandy clay	Semi-impermeable layer
3	11.1 – 35.5	Clayey sand	Semi-aquifer layer
4	35.5 – 63.5	Sand contains iron ore inserted with silt	Topsoil and shallow aquifer
5	> 63.5	Sand inserted with silt and gravel	Topsoil

Note: The position of WP-01 trajectory is 7.6855° S and 109.2560° E

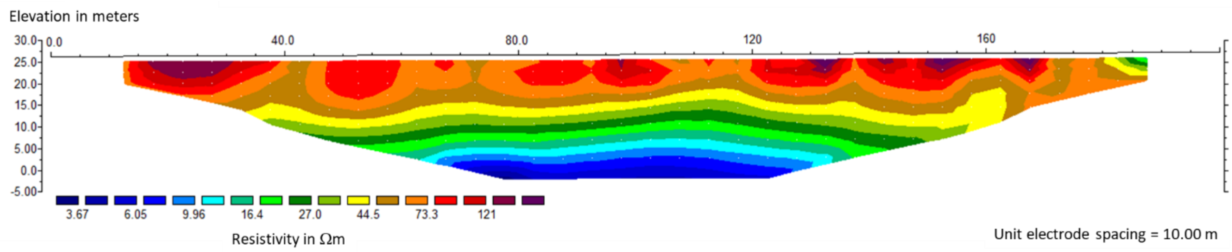

Figure 6. The 2D-resistivity profile contour obtained from inversion modeling on WP-02 trajectory

Table 2. The results of interpretation of the 2D-resistivity profiles on the WP-02 trajectory

No.	**Resistivity (Ωm)**	**Interpretation of Hydrogeology**	
		Lithology	**Hydrology**
1	< 6.05	Sand	The deep aquifer (intruded by saltwater)
2	6.05 – 16.4	Sandy clay	Semi-impermeable layer
3	16.4 – 27.0	Clayey sand	Semi-aquifer layer
4	27.0 – 73.3	Sand contains iron ore inserted with silt	Topsoil and shallow aquifer
5	> 73.3	Sand inserted with silt and gravel	Topsoil

Note: The position of WP-01 trajectory is 7.6859° S and 109.2597° E

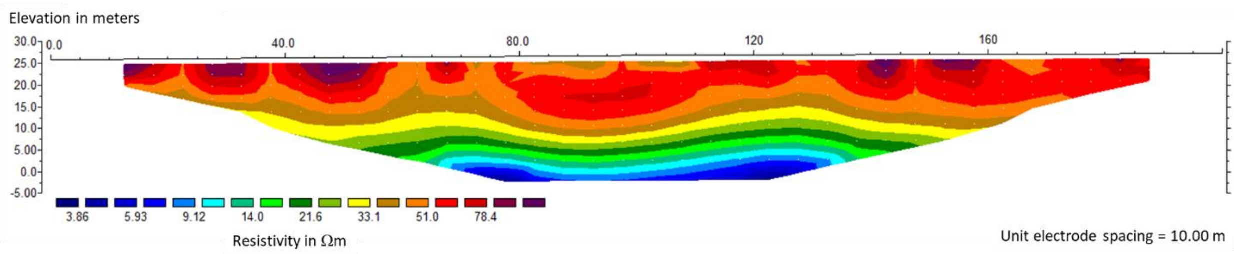

Figure 7. The 2D-resistivity profile contour obtained from inversion modeling on WP-03 trajectory

Table 3. The results of interpretation of the 2D-resistivity profiles on the WP-03 trajectory

No.	Resistivity (Ωm)	Interpretation of Hydrogeology: Lithology	Hydrology
1	< 5.93	Sand	The deep aquifer (intruded by saltwater)
2	5.93 – 14.0	Sandy clay	Semi-impermeable layer
3	14.0 – 33.1	Clayey sand	Semi-aquifer layer
4	33.1 – 51.0	Sand contains iron ore inserted with silt	Topsoil and shallow aquifer
5	> 51.0	Sand inserted with silt and gravel	Topsoil

Note: The position of WP-01 trajectory is 7.6865° S and 109.2627° E

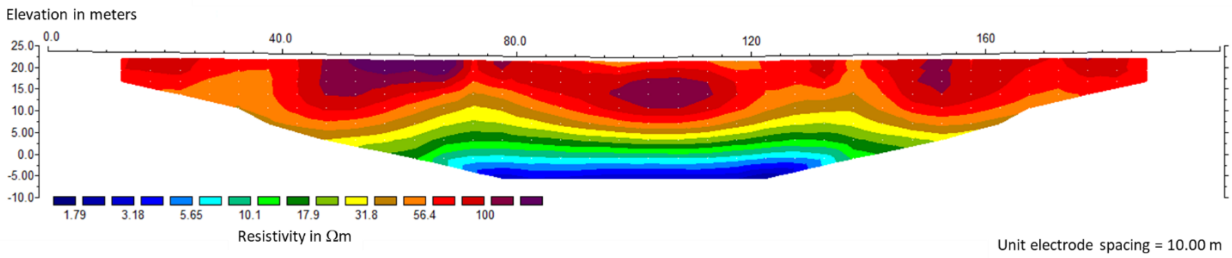

Figure 8. The 2D-resistivity profile contour obtained from inversion modeling on WP-04 trajectory

Table 4. The results of interpretation of the 2D-resistivity profiles on the WP-04 trajectory

No.	Resistivity (Ωm)	Interpretation of Hydrogeology: Lithology	Hydrology
1	< 5.65	Fine sand	The deep aquifer (intruded by saltwater)
2	5.65 – 17.9	Sandy clay	Semi-impermeable layer
3	17.9 – 31.8	Clayey sand	Semi-aquifer layer
4	31.8 – 56.4	Sand contains iron ore inserted with silt	Topsoil and shallow aquifer
5	> 56.4	Sand inserted with silt and gravel	Topsoil

Note: The position of WP-01 trajectory is 7.6928° S dan 109.2587° E

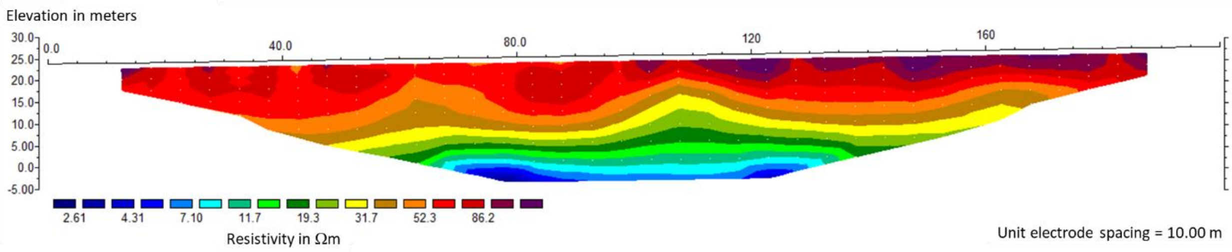

Figure 9. The 2D-resistivity profile contour obtained from inversion modeling on WP-05 trajectory

Table 5. The results of interpretation of the 2D-resistivity profiles on the WP-05 trajectory

No.	Resistivity (Ωm)	Interpretation of Hydrogeology: Lithology	Hydrology
1	< 7.10	Fine sand	The deep aquifer (intruded by saltwater)
2	7.10 – 11.7	Sandy clay	Semi-impermeable layer
3	11.7 – 31.7	Clayey sand	Semi-aquifer layer
4	31.7 – 52.3	Sand contains iron ore inserted with silt	Topsoil and shallow aquifer
5	> 52.3	Sand inserted with silt and gravel	Topsoil

Note: The position of WP-01 trajectory is 7.6945° S dan 160.9190° E

Design of Hydrogeological Profile

Based on the results as shown in the tables above, the hydrogeological model of sub-surface rocks needs to be designed. This design is based on the 2D-resistivity profiles shown in Figure 5 to Figure 9, and the results of its interpretation can be seen on the tables. The resistivity values of some layers having similar interpretation are grouped into one type of rocks [17]. Based on the obtained results, the hydrogeological profile model in this research site is interpreted to consist of five rock types, as listed in the tables.

All of those rocks are still covered in the alluvium formation, in accordance with the geological map of the research area [14]. The alluvium deposits that occupy this area consist of silts, clays, sands, gravels, gluttony, and rocks as the results of the erosion of the Karangbolong Mountains deposited by the flows of several rivers into this area. The alluvium deposits that occupy the southern part of the research site consist of sand, which are well-separated and very loose, showing that a layer model where iron sand resources can be found [18, 19]. The design results of the 2D-hydrogeological profile can be seen in Figure 10 to Figure 14.

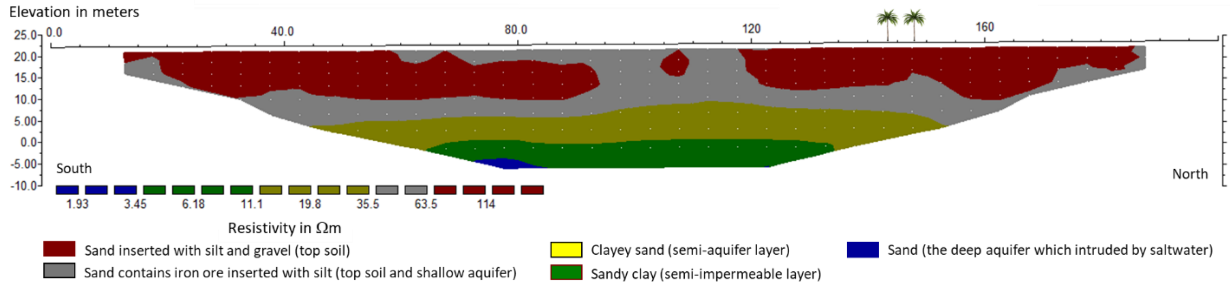

Figure 10. The 2D-hydrogeological profile contour of sub-surface rocks on the WP-01 trajectory

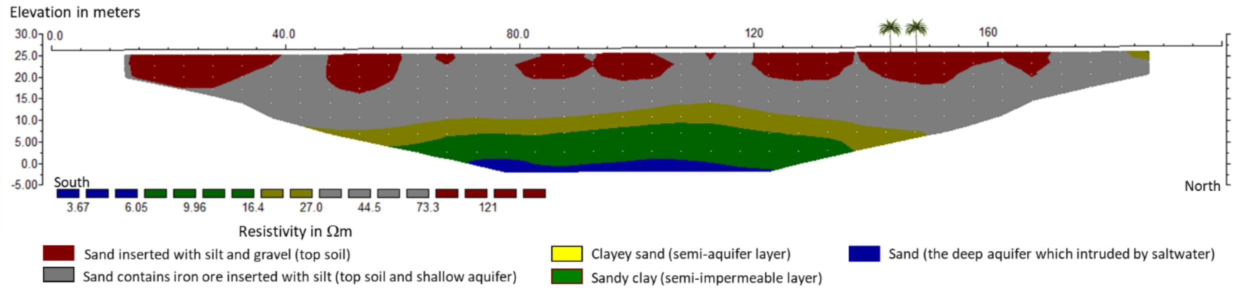

Figure 11. The 2D-hydrogeological profile contour of sub-surface rocks on the WP-02 trajectory

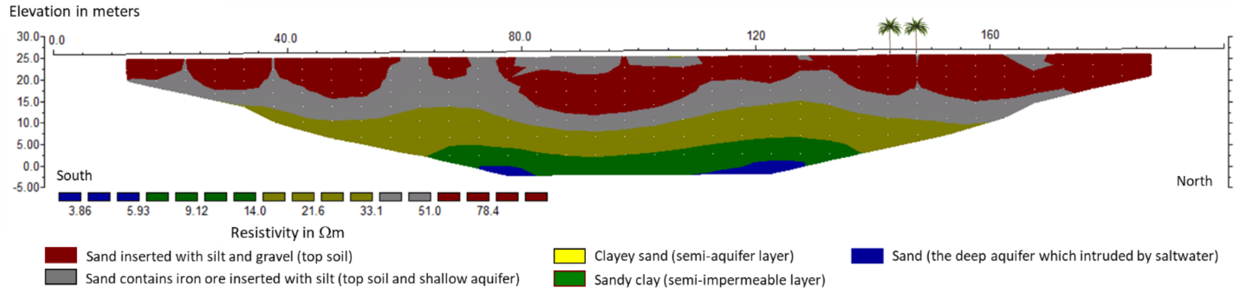

Figure 12. The 2D-hydrogeological profile contour of sub-surface rocks on the WP-03 trajectory

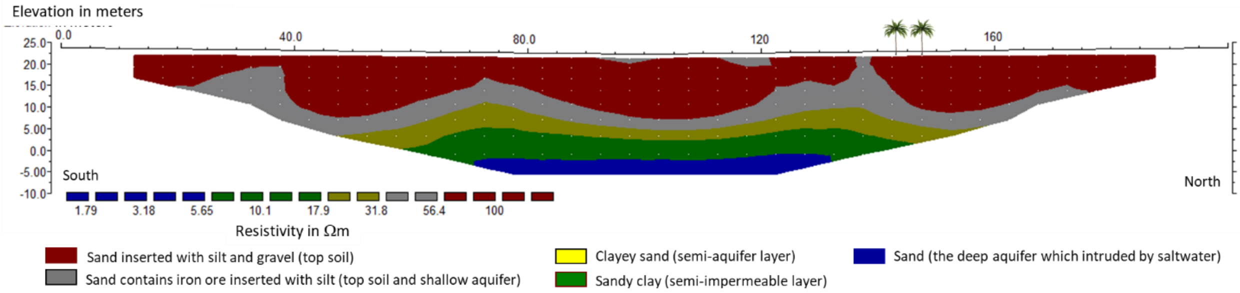

Figure 13. The 2D-hydrogeological profile contour of sub-surface rocks on the WP-04 trajectory

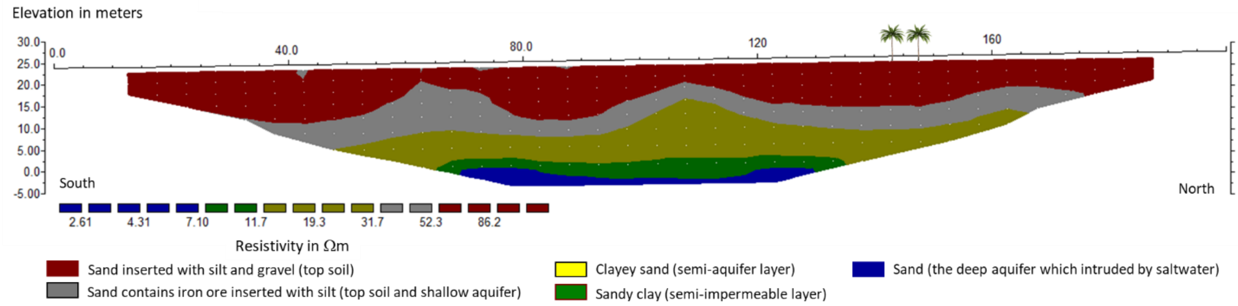

Figure 14. The 2D-hydrogeological profile contour of sub-surface rocks on the WP-05 trajectory

Based on the hydrogeological profile, the deep aquifer is believed to be intruded by saltwater. It is based on the small resistivity value and the generality of the coastal area where the deep aquifer is directly connected to the sea as the discharge area [20]. Besides that, the shallow groundwater aquifers are inferred mostly to have not been intruded by saltwater. This is supported by the fact that there is no salty well water in the research area. Naturally, seawater intrusion has occurred in the deep aquifers through the hydraulics relationship between groundwater and saltwater [21]. The high pressure and density of saltwater causes it to move to the deep aquifers. Based on the hydrogeological profile, saltwater flowing from the deep aquifers to shallow aquifers in this area was not found.

Based on the results of sub-surface rocks resistivity data [22], the iron sand is found in the second sub-surface layer, even partially on the surface. Specifically for the WP-02 trajectory, the iron sand layers are interpreted quite thickly, which indicates that this area has a large iron ore potential. The first layer consisting of sand inserted with silt and gravel is also found in iron ore at random basis. One of the dominant minerals in iron sand in the research area is magnetite (Fe_3O_4) [23].

The sand layer containing iron ore is a major part of the shallow aquifer. Therefore, iron sand mining activities in this area are believed to damage aquifers if there is not strict control. The impact of mining activities is such as the decrease in aquifer function in storing of groundwater, thereby reducing the flow of groundwater into the wells. This condition may lead into freshwater crisis and drought during the dry season as it used to happen Widarapayung Kulon village, District of Binangun, Cilacap Regency. In fact, before the iron sand mining activities took place, this area had never experienced such water crisis [24].

The results of this research are expected to be the reference for the government regarding the potentials of the sub-surface natural resources in the research site, i.e. iron ore. In addition, the government and mining companies are able to obtain the relevant information regarding the impact of iron sand mining activities based on the results of this research. The government is expected to be able to enact regulations to manage and control the iron sand mining activities, so these activities will not damage the environment, especially the aquifers in the coastal area. In addition, the publication of the results of this research is also expected to have an impact on the dissemination of the research that supports the development of science and technology in the geophysical exploration.

IV. CONCLUSION

Geophysical survey with 2D-resistivity method has been carried out in the prospect area of iron ore in the Widarapayung coastal area, Cilacap Regency, Central Java, from March to August 2018. The results obtained in the research are the resistivity and hydrogeological profiles of sub-surface rocks in the research site in the coastal area. Based on the resistivity profile, the resistivity values of the research area ranged from 1.79-121 Ωm. Based on the hydrogeological profile, sub-surface rocks in the research site consist of sand inserted with silt, gravels and gluttony, sand inserted with silt that contains iron ore, clayed sand, sandy clay, and fine sand intruded by saltwater. Based on the analysis, sand containing iron ore is the main material of shallow aquifers, so that iron sand mining activities are potentially to damage the aquifers and reduce their function in storing and flowing groundwater.

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