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RESEARCH ARTICLE

Resistivity Method for Characterising Subsurface Layers of Coastal Areas In South Sulawesi, Indonesia

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Abstract

The data presented in this paper are related to the characterization of a subsurface layer of coastal area in South Sulawesi. This research will fill the gap in the resistivity method study which is this method not yet use in the coastlines area, especially area influenced by seawater and coastal condition impact like South Sulawesi. The method used in this study is the method of resistivity Wenner configuration by taking the data 1-2 lines each region with lengths 45 m, 75 m, 105 m, and 120 m respectively. Data processing using non-linear least square optimization with that of the 2D inversion software Res2Dinv. The results show that the area is underlain by two layers of lithologic sections. In some sections interpreted by sandy layer, clay, sandstone, alluvium, sandy in seawater and metal minerals. From the analysis of the layers, all regions show the resistivity minimum is 0.00849 Ωm and 8.04 Ωm maximum resistivity. The result of this research can give n insight to study the large coastal area subsurface.

Keywords: Geo-electrical, Wenner configuration, coastal area, resistivity, subsurface layers.

1. Introduction

Rock lithology in an area has different types depending on the geological and climate conditions of the area. This paper focuses on examining subsurface lithology around the coast in 4regenciesand one city in South Sulawesi. Because South Sulawesi is one of the provinces with almost all areas having coastlines, researchers want to find out lithological information around the coastal area, especially wanting to investigate further the potential of quartz sand around the coast of South Sulawesi.

Geoelectrical methods are very commonly used in conducting subsoil or subsurface investigations for various cases. Many studies have been done on this subject as follows: geotechnical and engineering site investigations (Nur Islami, 2019); groundwater explorations (Island and Balaji, 2013)(Hafeez, Sabet and Zayed, 2018)(Rabeh et al., 2018)(Bayewu et al., 2018)(Aboh, 2015); mapping subsurface structures (Wo and Bania, 2019); mapping of soil and groundwater contamination (Xu et al., 2019)(Ganiyu et al., 2020); environmental studies (Wilson, Ingham and Mcconchie, 2006)(Kumar, Priju and Prasad, 2015)(Fadili et al., 2017); mapping of growth fault (Khalili and Mirzakurdeh, 2019); soil characterization for engineering purposes (Arjwech et al., 2020)(An et al., 2020)(Abudeif et al., 2019); ore deposit explorations (Arjwech et al., 2020)(Youssef, El-gawad and Farag, 2018)(Hariri et al., 2019); archaeological investigations (Yilmaz et al., 2019); bedrock detections (Woźniak and Bania, 2019).

The geoelectrical method is a method used to determine the nature of electric current in the earth by detecting it on the earth's surface. This detection involves measuring the potential, current and electromagnetic fields that occur either by injection current or naturally. One of the geoelectrical methods used in the measurement of electric current and to study the subsurface geological conditions is the resistivity method. The Wenner resistivity-meter is a measurement device using Wenner configuration to determine the apparent resistivity of concrete facings. Measurements are assumed to be carried out on a semi-infinite homogeneous material (Bonnet and Balayssac, 2018).

This research will fill the gap in the resistivity method study which is this method not yet use in the coastlines area, especially area influenced by seawater and coastal condition impact like South Sulawesi. This research's main targets aredetermining the subsurface structures and lithology of the investigated site in the coastal area, which is 4 regencies and one city in South Sulawesi, Indonesia; Pinrang Regency, Barru Regency, Maros Regency, Pare-pare City, and Bone Regency. The result of this research can give new information to use resistivity method in the coastal area and additional insight to find mineral potency in South Sulawesi or another area which have large coastal area.

2. Methods and Materials

A geoelectrical survey was done using the resistivity method with Wenner configuration. Data is collected by using a Single Channel Resistivity. The Wenner resistivity-meter is a measurement device using Wenner configuration to determine the apparent resistivity of concrete facings. Measurements are assumed to be carried out on a semi-infinite homogeneous material (Bonnet and Balayssac, 2018). The Wenner method consists of four equispaced electrodes and the tips are placed in contact with the concrete surface. A current is sent through the two outer electrodes (Figure 1). By measuring the voltages through the inner electrodes, the apparent resistivity is calculated through Ohm’s Law and the solution is given by the following equation:

$$\rho = \frac{KV}{I} \qquad (1)$$

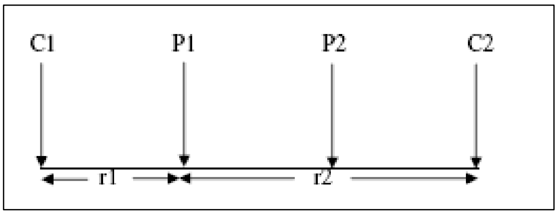

Fig 1. Current and potential electrodes in the Wenner configuration (Aboh, 2015).

From the Figure 1, it can be seen that the distance C1PI = P2C2 = a and the distance C1P2 = P1C2 = 2a, using equation (1). where ρ is the apparent resistivity, a is the electrode spacing, V is potential measured between the inner probes and I the current applied through the outer electrodes (Presuel-Moreno, Liu and Wu, 2013) and K is Wenner configuration factor (equation 2).The length of C1C2 and P1P2is5 meters. The location is on the edge of a river that has slightly watery soil conditions. Data collection conditions with sunny weather or dry season. Data collection was carried out on Sunday,24 March2020.

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

This research was conducted in March 2020 using the resistivity method with a Wenner configuration. Measurements were made 1 – 2 lines each location with lengths consist of 45 m, 75 m, 105 m, and 120 m. The location area shown located at the beachside is shown in Figure 2 and the coordinate location of each point is shown in Table 1. We chose five locations that assumed representative of coastal area in South Sulawesi. The data analysis process was carried out to obtain a 2D cross-section and subsurface resistivity values. Then the process of data interpretation is done by adjusting the geological conditions at the study site and connecting by the list of the Telford table resistivity (Table 2). Images for the resistivity survey are presented as the cross-section of the resistivity profile. The data were interpreted by comparing with the geology of the area (Figure 5) and matching with values of electrical resistivity of earth materials. Rock boundaries indicated on the resistivity profiles are certainly based on the available lithological borehole information. The images obtained, which are based on the 2D inversion of the field data. The color bar indicates the range of electrical resistivity values in the unit of ohm-meters (Ωm). The color scale is logarithmic and consistent with contour intervals (Arjwech et al., 2020).

Thisstudy focusesonthe measurement of the field by resistivity meter. The number of data measurements isfive of the data field.

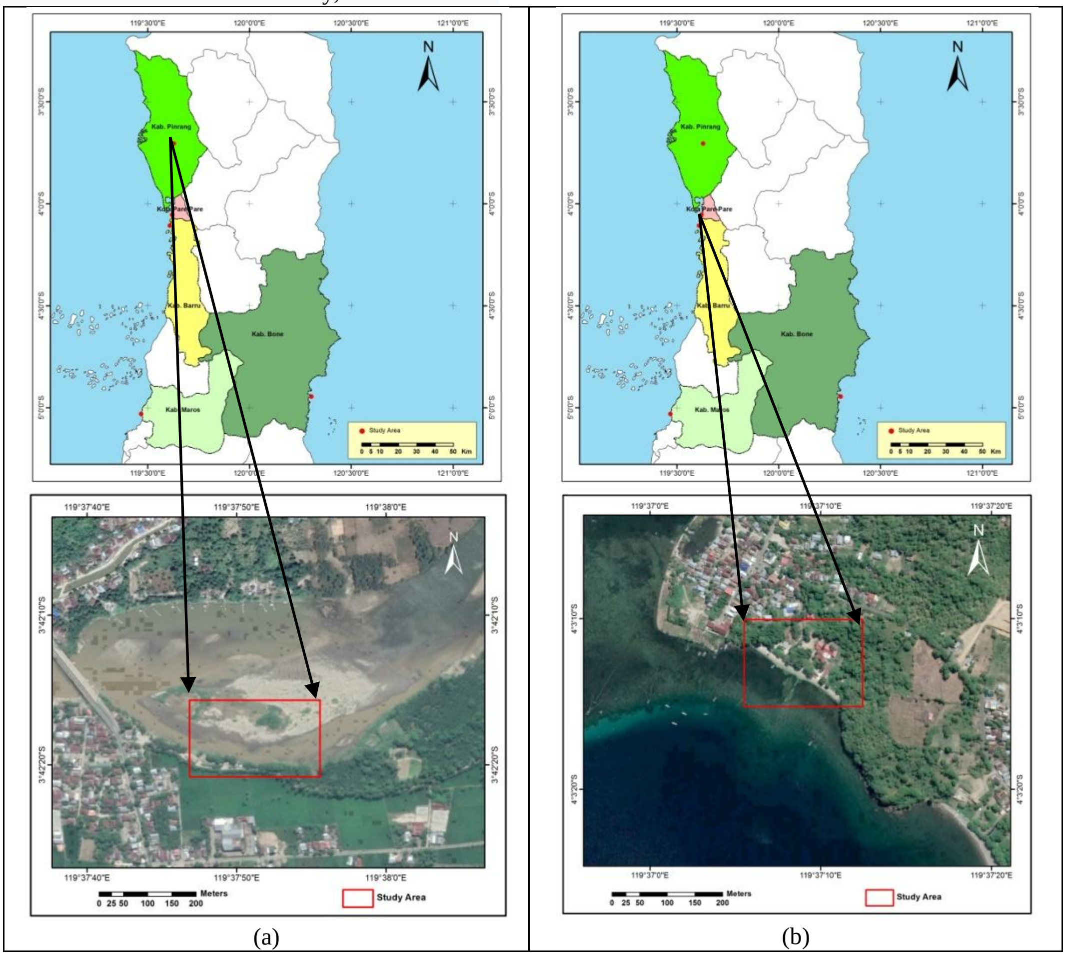

Fig 2. Maps location study area: (a). Pinrang regency; (b). Pare-pare city

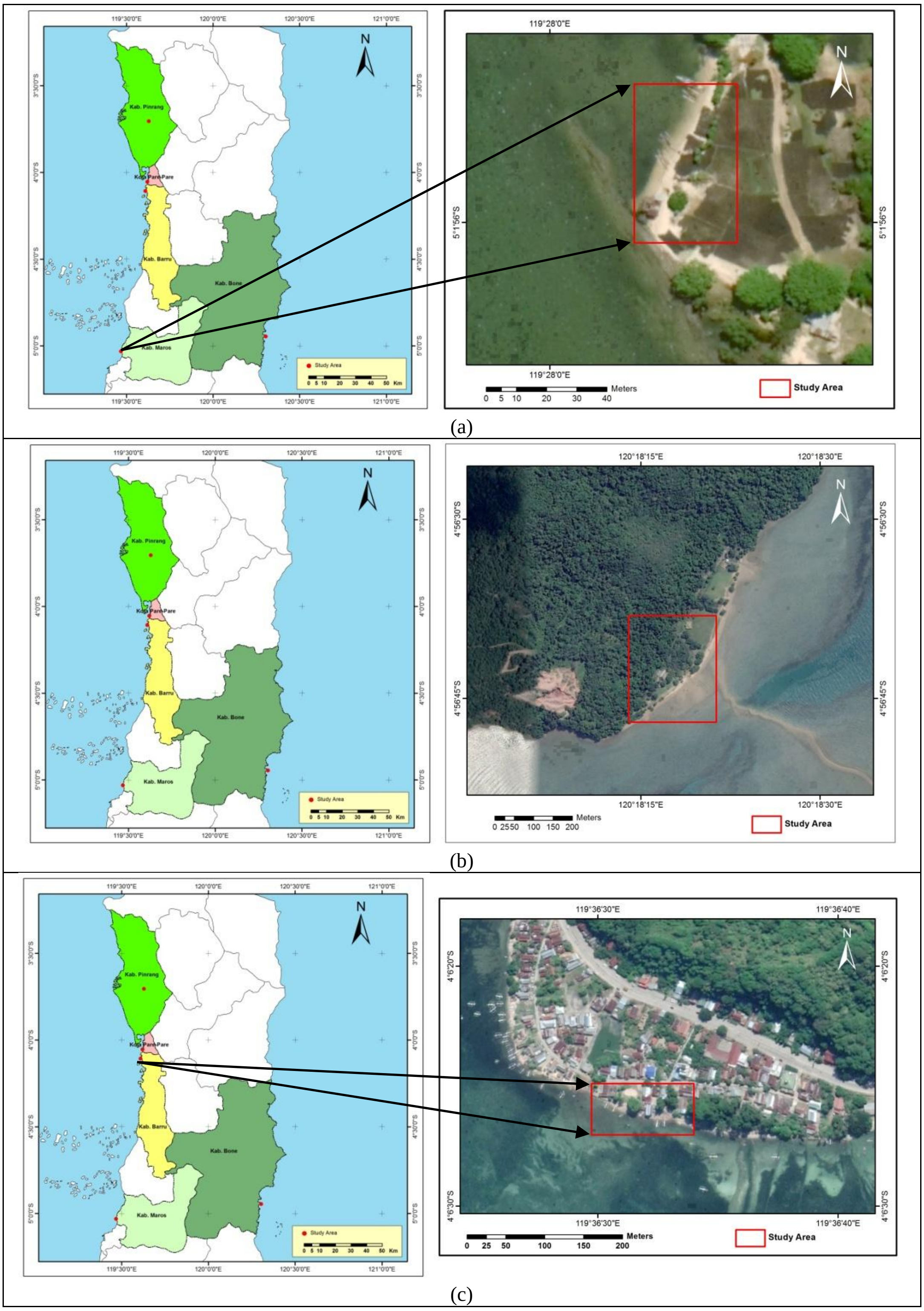

Fig 3. Maps location study area: (a). Maros regency; (b). Bone regency; (c). Barru regency.

Table 1. GPS and elevation

Point	GPS		Location
	Latitude	Longitude	
1	3º 42' 17"	119º 37' 46"	Pinrang
2	4º 3' 11.9"	119º 36' 7.3"	Parepare
3	4º 3' 13.7"	119º 37' 10.3"	Parepare
4	5º 1' 55.7"	119º 28' 01.3"	Maros
5	5º 1' 51.6"	119º 28' 01.9"	Maros
6	4º 56' 45.6"	120º 18' 15.3"	Bone
7	4º 56' 43.4"	120º 18' 18.4"	Bone
8	4º 6' 26.6"	119º 36' 31.5"	Barru

Table 2. Resistivity of minerals (W.M.Telford, 1990)

Materials	Resistivity (Ohm-Meter)
Pyrite	0.01 – 100
Quartz	500 - 800.000
Calcite	1 x 1012 - 1 x 1013
Rock Salt	30 - 1 x 1013
Granite	200 - 100.000
Andesite	1.7 x 102 - 45 x 104
Basalt	200 - 100.000
Limestone	500 - 10.000
Sandstone	200 - 8.000
Shales	20 - 2.000
Sand	1 - 1.000
Clay	1 – 100
Ground Water	0.5 – 300
Sea Water	0.2
Magnetite	0.01- 1.000
Dry Gravel	600 - 10.000
Alluvium	10 – 800
Gravel	100 – 600

3. Result and Discussion

Resistivity measurements at the five points show inversion two-dimension results processed by Res2DInv software. The interpretation of the electrical resistivity tomography section is based on Table 2 and the geological condition around the data acquisition point.

Pinrang regency is the first point in this research. In this location, measure with 1 line which length of a line is 105 m with 5 m electrode spacing. The processing used in 3 iterations and got 5.3% on error. It is accepted on resistivity inversion processing.

The resistivity section (Figure 5) has depth with a range of 1.25 to 17.3 m and a resistivity range between 2.65 and 35.4 Ωm. It can be interpreted as two layers. The first layer is characterized by relatively high electrical resistivity ranges, from 8.04 to 35.4 Ωm. This layer was interpreted as sand until 17.3 m depth. On other hand, the second layer is characterized as a boulder by resistivity result between 2.65 and 5.55 Ωm is a shaly-sand layer. The depth of this layer is around 6.76 to 17.3m.

A mineral or rock has a different resistivity value, the size of the resistivity of rock and mineral depends on the factors that influence it and the electrical properties of the rock or mineral itself. The resistivity values for minerals or rocks that are conductors are in the range of 1-10^7 Ωm for example sand, silt, clay, sandstone, and granite. The resistivity value is large when the rock or mineral can conduct small electric currents and the resistivity is small when the rock or mineral ability is large.

Based on the geological map in Figure 4, namely the geological map of Majene and Palopo sheets, it is known that the rock composition of Pinrang Regency consists of alluvial deposits and andesitic sandstones. Alluvial deposits consist of sand, clay, silt, and gravel. It is known that sand is a material whose main mineral constituent is quartz, clay is a mineral containing fused quartz, and it is also known that the oldest alluvial will produce granite. Granite is an igneous rock that contains quartz. The interpretation of the resistivity section is confirmed by this explanation that Pinrang consists of sand and shaly-sand.

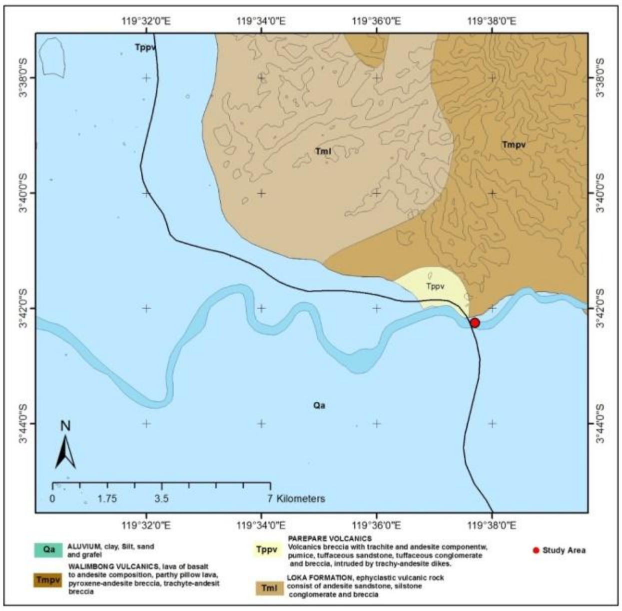

Fig 4. Geology Map Pinrang regency area

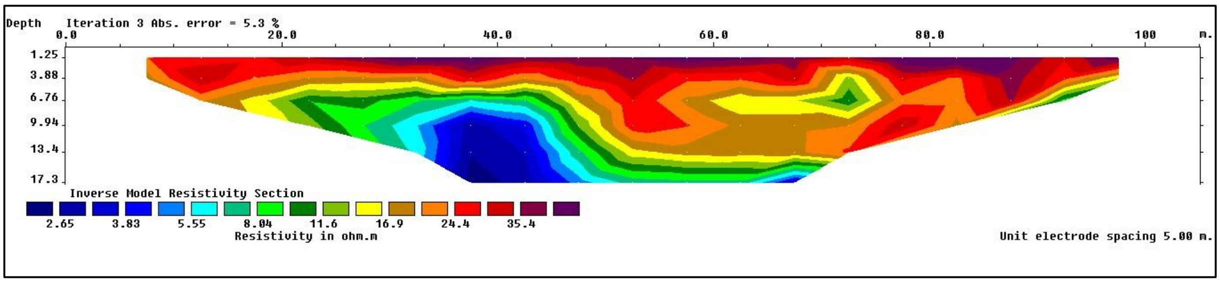

Fig.5. An inverse model resistivity section, Pinrang Regency area

Pare-pare city is the second point measurement. This location consists of 2 lines with 120 m and 75 m length with 5 m electrode spacing. The research location is located on the geological map of Pangkajene and Watampone Western Parts, Sulawesi with the Qac formation, are the Alluvium Deposition, Lake, and Coast(Van_Bemmelen, 1970).

The processing used by 5 iterations and got error are 16.7% on the first line and 23.6% on the second line. It is quite above standard but accepted on resistivity inversion processing. The resistivity section (Figure 5) consists of two lines. The first line has depth with a range of 1.25 to 19.8 m while the second line is 1.25 to 12.4 m. The resistivity range on the first line is lower than the second line, between 0.0849 to 14.5 Ωm.

Interpretation results by referring to the geological map (Figure 7) and table 2 can be assumed that on the first line (Figure 5, above) there is a type of layer with a resistivity value of 0.00849 – 0.177 Ωm, which is at the electrode position at a distance of 45–75 m, and the electrode position is 90–105m at a depth of about 2 – 20m. Meanwhile, at the resistivity value of 0.369 – 14.5 Ωm, it can be assumed that the alluvium, lake, and beach sediment layers are quartz sand filled with seawater so that the resistivity value is relatively small at a depth of 0–198 m.

In the second track (Figure 6, below) after geoelectric measurements have been made with a track length of 75 m, it can be assumed that the first layer is a layer of quartz sand with a resistivity value of 8.35 – 26.5 Ωm at a depth of 0–4m. while in the next layer, it is assumed that the sand contains seawater so that the resistivity value is relatively small, is 0.468 – 4.69 Ωm at a depth of 3 – 12.4 m.

It can show in Fig 5.The blue color meaning is the low resistivity value, the green and yellow colors indicate moderate resistivity values and red to purple indicates high resistivity values.

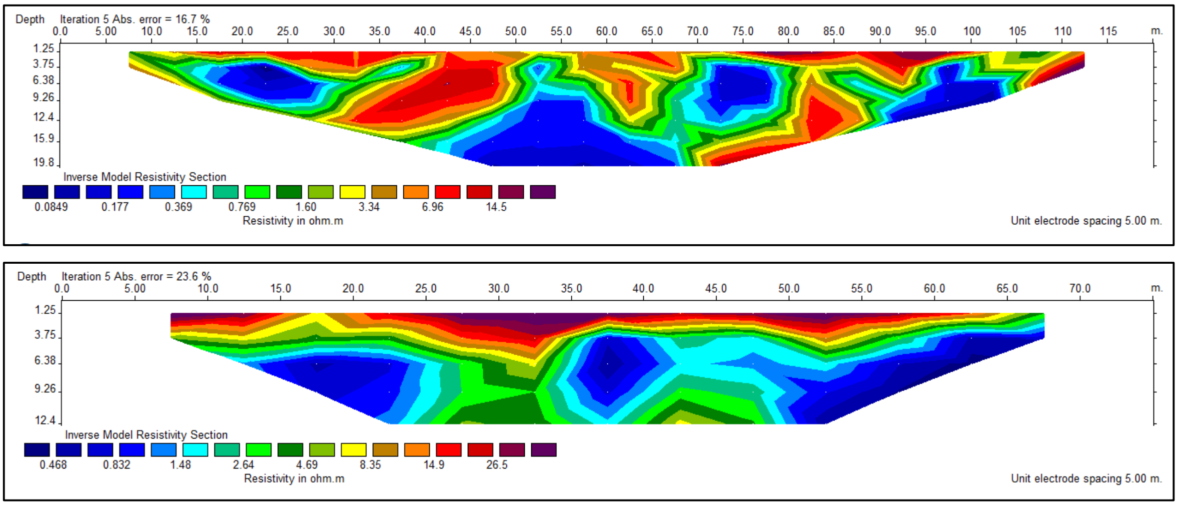

Fig 6. An inverse model resistivity section, Pare-pare city area. Above: first line; Below: second line.

This research was conducted in the Kuri Caddi Beach area, Nisombalia Village, Marusu, Maros Regency, South Sulawesi Province. The data obtained using the resistivity method with the Wenner configuration consists of 2 tracks with a track length of 120 m each with an electrode spacing of 5 m.

The processing used 5 iterations and got errors are 20.5% on the first line and 16.9% on the second line. It is accepted although quite above standard on resistivity inversion processing. The resistivity section (Figure 7) consists of two lines. All lines have depth with a range of 1.25 to 19.8 m. The resistivity range on the second line is lower than the first line, between 0.156 to 9.13 Ωm

Geological conditions based on Figure 9 (left), that the research location is in the Qac formation, namely the Alluvium and Beach Sediment Formation in the form of Gravel, Shaly-Sand, Mud, and Coral Limestone. After data processing and interpretation by referring to geological maps and resistivity tables, it can be assumed that the resistivity results show similar geological conditions. The first line is consists of two layers (Figure 7, above). The first layer is a layer of coastal sediment in the form of sand with seawater with a resistivity value of 0.302 – 0.956 Ωm, at a depth of 0 – 10 m. While the resistivity value of 1.70 – 17.0 Ωmcan be assumed as a layer of beach sediment in the form of sand at a depth of 3–19.8 m. In the second line (Figure 8, below) it can be assumed that the first layer is a layer of beach sediment in the form of sand with seawater inserts with a resistivity value of 0.156 – 0.892 Ωm which is located at a depth of 0 – 15 m. Layers with resistivity values of 1.60 – 9.13 Ωmcan be assumed to be a layer of beach sediment in the form of sand at a depth of 0 – 19.8 m.

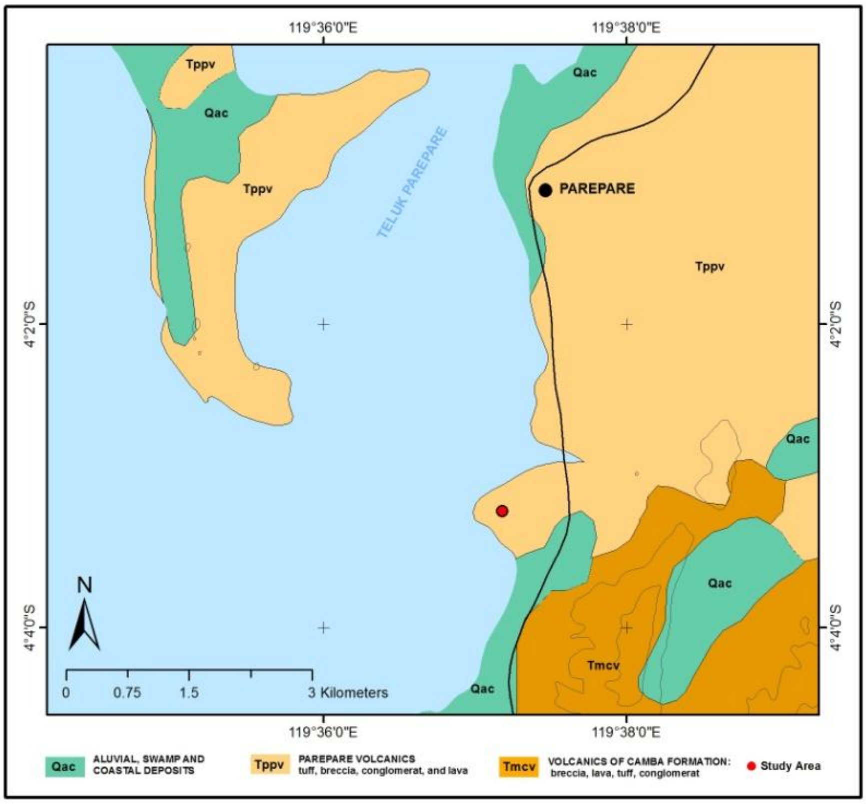

Fig 7. Geology Map Pare-pare city area

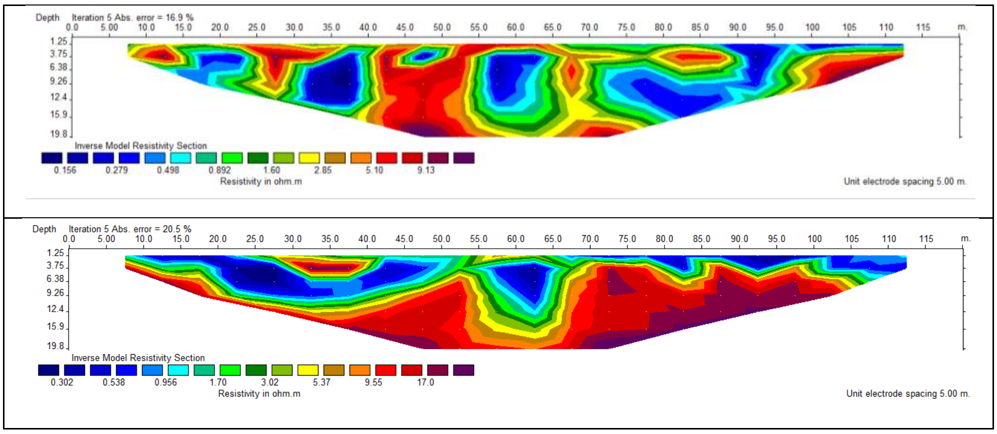

Fig 8. An inverse model resistivity section, Maros regency. Above: first line; Below: second line.

This research was conducted in the Tete Beach area, Bone Pute Village, Kec. Tonra Kab. Bone, South Sulawesi Province. The data obtained using the Resistivity method with the Wenner configuration consists of 2 lines each with a length of 120 m with an electrode spacing of 5 m.

The processing used in 5 iterations and got an error of around 26% on each line. It is accepted so it can continue to the interpretation step. The resistivity section (Figure 9) consists of two lines. All lines have depth with a range 1.25 to 19.8 m. The resistivity range on every line is very low, around 0.156 to 2 Ωm.

Geological conditions at the study site are in Figure 10 (right) with the type of formation Qac. Qac Formation: Alluvium and Coastal Deposits. In the results of measurements and data processing, a subsurface image in the form of a 2D cross-section is obtained. In the process of determining the type of subsurface structure, it can be done by observing the geological map of the research location and table 2. In the first line (Figure 8, above) there are several types of layers. The resistivity value of 0.126 – 2.01 Ωm can be assumed to be a layer of alluvium and beach deposits in the form of quartz sand with seawater inserted at a depth of 0 – 198 m. While the resistivity value of 0.0417 – 0.0725 Ωm can be assumed to be a mineral-containing layer because the dominant layer has a low resistivity value, which is at the electrode position of 15 – 25 m, 45 – 55 m, and 60 – 80 m.

In the second line, it can be interpreted that the resistivity value of 0.129 – 2.87 Ωm is suspected to be a layer of alluvium deposits and the beach is in the form of quartz sand with seawater inserted at a depth of 0 – 19.8 m. Meanwhile, at a resistivity value of 0.0374 – 0.0695 Ωm, it can be assumed that layers containing minerals are found at the electrode positions of 10 – 15 m, 45 – 60 m, and 75 – 85 m, the layer is suspected to be a mineral layer because the resistivity value is dominantly lower than the value of another resistivity.

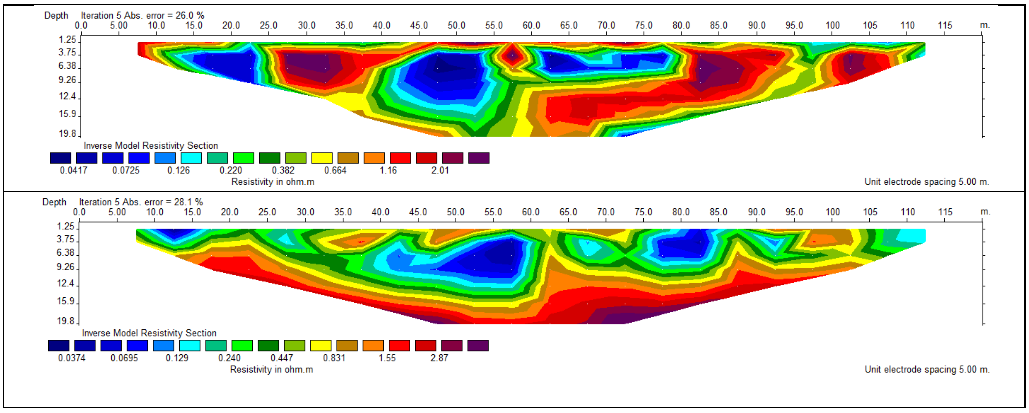

Fig 9. An inverse model resistivity section, Bone regency.

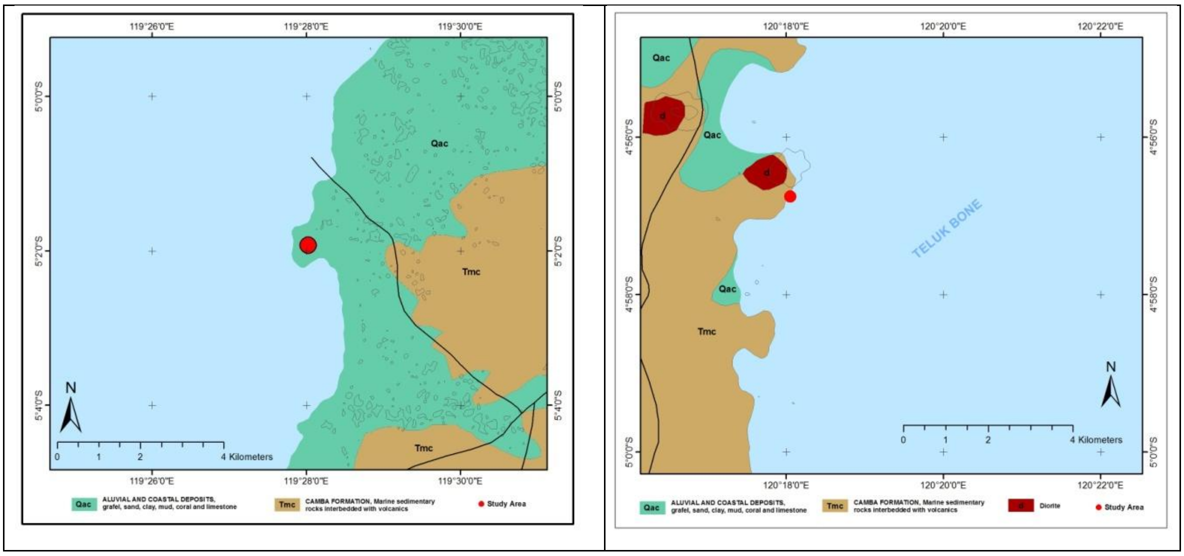

Fig 10. Geology Map.Left: Maros regency area;Right: Bone regency area.

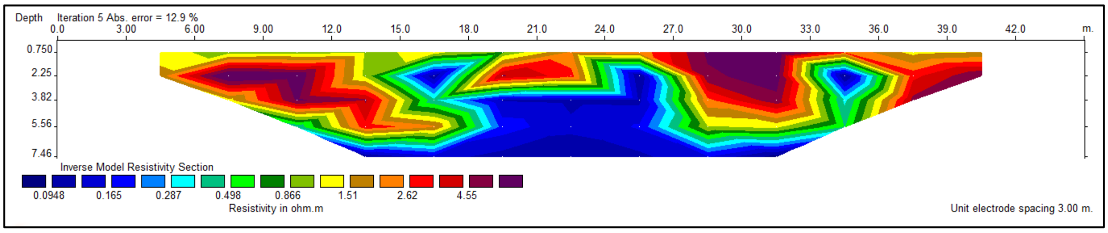

Fig 11. An inverse model resistivity section, Barru regency area

The last point in this research is Barru regency. This research was conducted in Kupa Village, Malluse Tasi, Barru Regency, South Sulawesi Province. The location of data collection in Barru regency is almost close to the location of data collection in the city of Pare-pare, which is the point of measurement carried out on the coast. Figures 10 show 1 line measurement using the Wenner configuration.The processing used by 5 iterations and got 12.9% on error. It is accepted on resistivity inversion processing.

The resistivity section (Figure 11) have depth with range 0.75 to 7.46 m and resistivity range between 0.0946 and 4 Ωm. The results of this line show two types of subsurface layers, the first layer in the form of quartz sand deposited with sea water which has a resistivity value of about 0.165 – 4.55 Ωm at a depth of 0 – 6 m. the second layer is obtained the resistivity value of 0.0948 Ωs. which is a layer that contains metal minerals at 2-∞ m depth. From this result also shows the similarity of data from research conducted in Barru regency (Ariansyah et al., 2020).At this location, only 7.46 m depth can be detected, due to the limited length of the line at the research site.

The geological conditions at the study site are in Figure 12 with the type of Qac formation. Qac Formation: Alluvium and beach deposits with lithology types of Gravel, Sand, Clay, Mud, and Coral Limestone. The resulting 2D cross-section confirms the geological conditions. Overall interpretation results indicate the presence of several materials such as a sandy layer, shale/clay, sandstone, alluvium, sandy in seawater, and metal minerals. From the analysis of the layers, all regions show the minimum resistivity is 0.00849 Ωm and the maximum is 8.04 Ωm. It shows in Table 3.

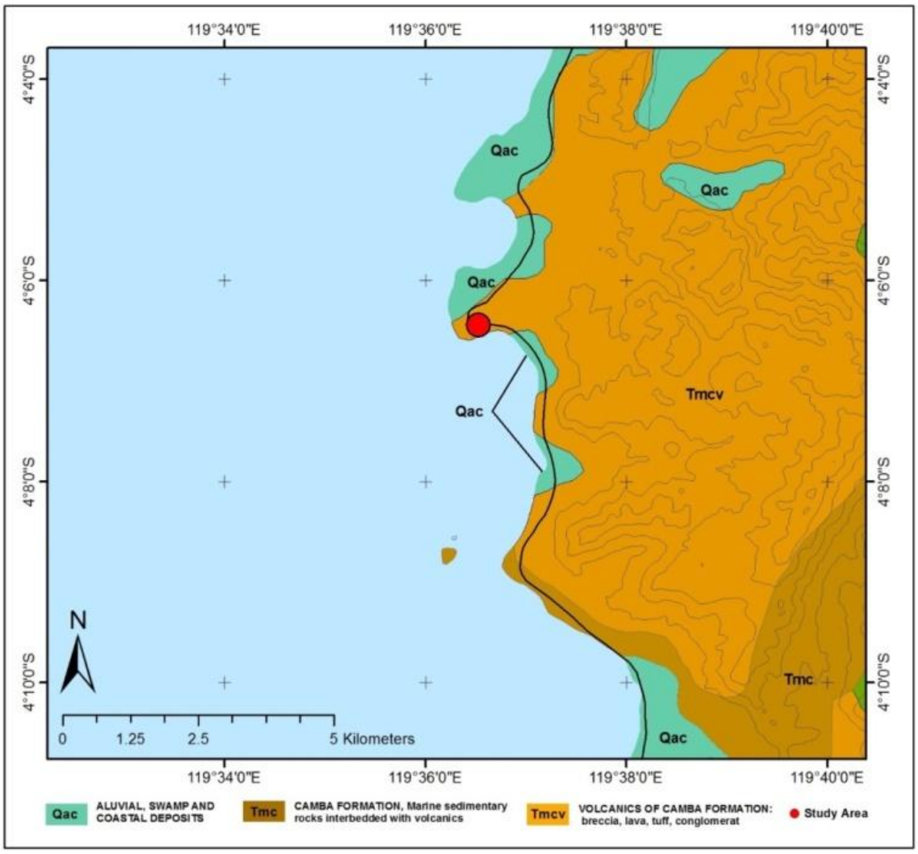

Fig 11. Geology Map Barru regency area

Table 3. Resistivity interpretation and their inferred lithologies.

Ves No.	No of Layers	Resistivity (Ohm-m)	Depth (m)	Inferred Lithology	Area / region
1	1	8.04-35.4	1.25-17.3	Sandy layer	Pinrang
	2	2.65-5.55	6.76-17.3	Shaly-Sand Layer	
2	1	0.00849 - 0.177	2-20	metal minerals	Pare-pare
	2	0.369 - 14.5	0 -19.8	sandstone in seawater	
3	1	8.35 - 26.5	0-4	sandy layer	Pare-pare
	2	0.468 - 4.69	3 - 12.4	sandy in seawater	
4	1	0.302 - 0.956	0 - 10	sandy in seawater	Maros
	2	1.70 - 17.0	3-19.8	sandy layer	
5	1	0.156 - 0.892	0 - 15	sandy in seawater	Maros
	2	1.60 - 9.13	0 - 19.8	sandy layer	
6	1	0.126 - 2.01	0 -19.8	alluvium layer	Bone
	2	0.0417 - 0.0725	2-15	metal minerals	
7	1	0.129 - 2.87	0 - 19.8	alluvium layer	Bone
	2	0.0374 - 0.0695	1.25 - 10	metal minerals	
8	1	0.165 - 4.55	0 - 6	Sandstone	Barru
	2	0.0948	2-∞	metal minerals	

Conclusions

In this research, the results show that the area is underlain by two layers of lithology sections. In some sections interpreted by sandy layer, shale/clay, sandstone, alluvium, sandy in seawater and metal minerals. From the analysis of the layers, all regions show the minimum resistivity is 0.00849 Ωm and the maximum is 8.04 Ωm. This result can give additional sightseeing and information on coastal development in the further.

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