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Identification of the Distribution of Seawater Intrusion Using the Resistivity 2D Method in the Belawan Area, North Sumatra Province

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ABSTRAK

Pengambilan airtanah dalam yang berlebihan berdampak pada berubahnya arah aliran airtanah sehingga tekanan hidrostatis menurun, sehingga terjadi intrusi air laut. Penelitian ini bertujuan untuk mengetahui daerah teriindikasi adanya intrusi air laut dan mengetahui arah sebaran kontaminan air asin. Metode yang digunakan metode geolistrik resistivitas konfigurasi Schlumberger untuk mendapatkan nilai resistivitas dengan panjang lintasan 200 meter. Pada hasil penelitian yang didapat di lapangan, pengolahan menggunakan Ms. Excel dan diinterpretasikan menggunakan IP2WIN. Hasil pengolahan menggunakan IP2WIN kemudian diolah menggunakan Surfer untuk menarik korelasi antara Track I dan Track III dalam bentuk 2D. Jalur I yang terindikasi intrusi air laut yaitu pada lapisan ketujuh dengan nilai resistivitas 0,198 m ditetapkan sebagai intrusi air laut. Track II menunjukkan intrusi air laut yaitu pada lapisan keenam ditemukan intrusi air laut dengan nilai resistivitas 0,0584 m. Track III menunjukkan adanya intrusi air laut yaitu pada lapisan kedelapan ditemukan air laut dengan nilai resistivitas 0,0035 m. Berdasarkan penelitian yang dilakukan, sebaran intrusi air laut dari Track I di Jalan Raya Belawan Pelabuhan Belawan, Desa Bagan Deli, Kecamatan Medan Belawan, yang dekat dengan pantai. Intrusi air laut mengalir ke arah barat daya yang merupakan lokasi Track II dan Track III melalui lapisan airtanah yang terkena intrusi.

Kata kunci: Airtanah, Intrusi air laut , Geolistrik 2D, Resistivitas, Akuifer, Potensi airtanah, Belawan

ABSTRACT

Excessive withdrawal of deep groundwater has an impact on changing the direction of groundwater flow so that the hydrostatic pressure decreases, resulting in seawater intrusion. This study aims to determine the areas indicated by seawater intrusion and determine the direction of distribution of saltwater contaminants. The method used is the Schlumberger configuration resistivity geoelectric method to obtain resistivity values with a path length of 200 meters. In the research results obtained in the field, processing using Ms. Excel and interpreted using IP2WIN.. The results of the processing using IP2WIN are then processed using Surfer to draw the correlation between Track I and Track III in 2D form. Line I which indicated seawater intrusion, namely the seventh layer with a resistivity value of 0.198 m, was designated as seawater intrusion. Track II shows seawater intrusion, namely in the sixth layer seawater intrusion is found with a resistivity value of 0.0584 m. Track III shows the presence of seawater intrusion, namely in the eighth layer seawater is found with a resistivity value of 0.0035 m. Based on the research conducted, the distribution of seawater intrusion from Track I on Jalan Raya Belawan, Belawan Harbor, Bagan Deli Village, Medan Belawan District, which is close to the beach. Seawater intrusion flows to the southwest which is the location of Track II and Track III through the groundwater layer affected by the intrusion.

Keywords: Groundwater, Seawater intrusion, 2D geoelectric, Resistivity, aquifer, potential groundwater, Belawan

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1. INTRODUCTION

The development that occurs in the North Sumatra region is strongly influenced by the vast coastal area which is widely used as a location for industry, companies and also trade. With the increasing economy and progress in the region, the need for clean water is also increasing due to the development of the population which is increasing continuously every year (Hadi, A. I, et al., 2009).

Excessive use of ground air in coastal areas will have a negative impact on the hydrological system (Alfaiz &Hutahaean, 2015), one of which is sea air intrusion. Sea water intrusion is a very important problem to be studied further (S Purnama & Marfai, 2012). Sea water intrusion occurs due to changes in ground water pressure so that sea water can move towards land. Changes in hydrostatic pressure between ground air and sea air which are unbalanced cause sea air intrusion (Saila & Azmeri, 2013). Changes in groundwater pressure can occur due to several things, namely rising sea levels, reduced supply of groundwater from the mountains and excessive exploitation of groundwater (Minarto et al., 2016). Developing cities located on the coast have higher potential for groundwater contamination in the form of seawater intrusion (Afrianita et al., 2017). Seawater intrusion can cause changes in the physical, biological and chemical properties and content of groundwater (Cahyadi et al., 2017).

Clean water is a very important need for humans because it is needed continuously for daily activities. Therefore, humans need water sources both from surface water and underground water (Kencanawati.et al.,2017). Surface water is water that is above the ground water surface, in a stationary or flowing condition. While groundwater is water contained in a porous soil layer (aquifer) or in rocks below the soil surface (Maizir, 2019).

The higher the water demand needed by the community, the groundwater extraction is carried out. Excessive deep groundwater extraction can have an impact on changes in the direction of groundwater flow so that hydrostatic pressure will decrease and seawater intrusion will occur. Seawater intrusion is the entry of seawater into the groundwater aquifer so that groundwater conditions become salty like seawater. Seawater intrusion can have a negative impact on daily activities and can interfere with human health (Herdyansah, A., et al. 2017). (Wadhana et, al. 2017), explains that Water Soil comes from nature and plays an important role as the main source of water

used to meet water needs clean. Intrusion often occurs in coastal aquifers, this occurs when the groundwater level in freshwater aquifers is lower than the average sea level so that seawater will push freshwater towards the land causing the taste of freshwater to become salty (Rahmawati,2013; Tabita Abid,2016;Adeyemo I.A., et al,2017) To identify the spread of seawater intrusion on the coast of Belawan, you can use geophysical methods that study the electrical properties of materials below the earth's surface called geoelectricity. The principle used in the geoelectric measurement method is to inject electric current into the ground surface. This provides information in the form of rock resistivity (Wijaya, A., 2015). While data processing and interpretation in 2 Dimensional (2D) cross sections (Ardaneswari.et al. 2016)

By knowing the resistivity (type resistance) of the rock, we can know the subsurface geological conditions related to the composition of the fluid and the porosity of the rock in the soil, and we can know the layers of rock or rock material that are in the ground. Areas indicated by seawater intrusion and resistivity values are track-1, track-II and track-III, distribution of seawater intrusion in the coastal collar of the coastal area, trending southwest to northeast.

2. METHODS

2.1. Research Location and Time

This research is located in the Belawan area, Medan Belawan District, Medan City, North Sumatra Province, (Figure 1) and geographically it is located at coordinates 03^{o}45'50" LN, 98^{o}41'12" EL. Geoelectric is a tool used to get the resistivity value of soil/rock layers at measurement points, consisting of alluvial, gravel and sand Figure 4. The resistivity value will then be analyzed using the IP2WIN program so that the real resistivity value of each point in the cross section, layer thickness and layer depth is obtained. Data collection in the study was carried out at three locations with a track length of 200 meters with overlapping 3 times with the aim of getting a resistivity value with a depth that can reach deep groundwater. The research was carried out on 28-30 July 2021. location point as shown in Figure 1.

Figure 1. Research Locations in Medan Belawan District

Determination of the location of the trajectory is determined by a topographic map. By knowing the topography of the area, it can be seen the elevation of the Belawan field and the direction of the water flow can be known. The topographic map of the Medan Belawan sub-district is as follows.

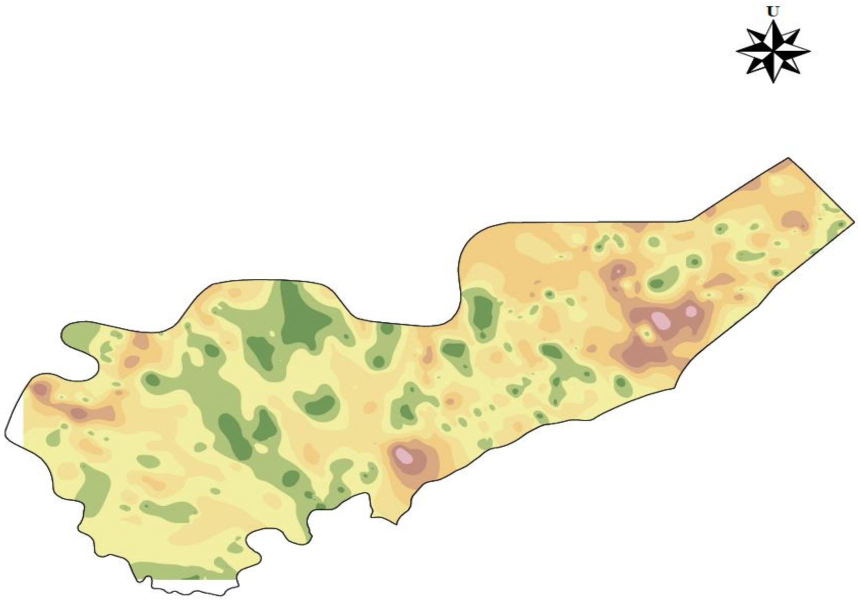


Figure 2. Topographic Map Medan Belawan

Description:
= Height 7 – 9 meter above sea level
= Height 4 – 6 meter above sea level
= Height 1 – 3 meter above sea level

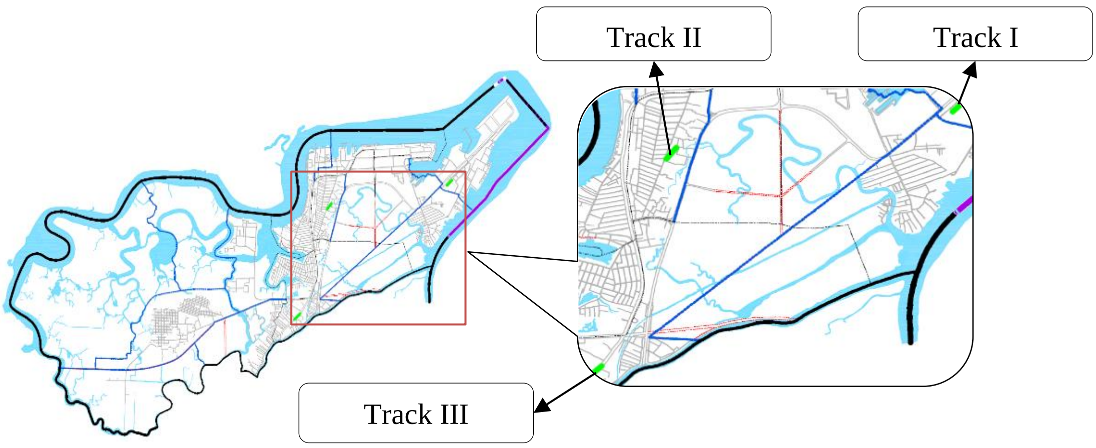
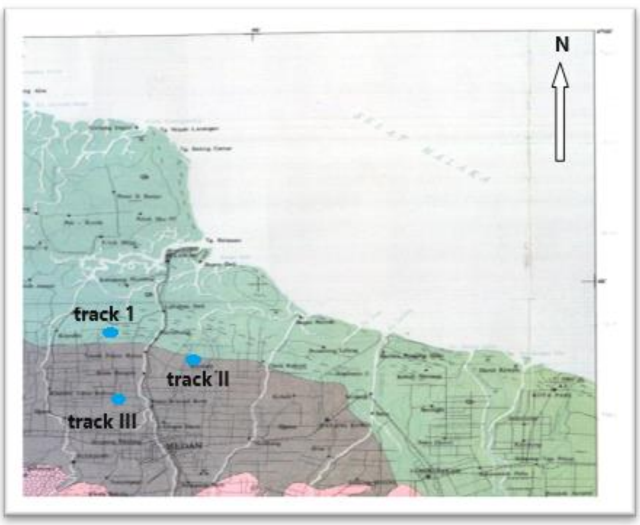


Figure 3. Location of the track in Medan Belawan District



Legend :

Track	Simbol	Discription
1	Qh	Alluvial:gravels,sands,clays
2	Qpme	Boulder, gravels sand,clay
3	Qvt	Tuff riodacite

track :I,II,III

Figure 4. Geological Map of Medan Belawan District

2.2. Research Equipment

One unit of Neorisist Geoelectric measuring instrument – HJ3454 consists of: Neoresist Resistivitymeter – HJ3454, Switchbox, current and potential electrodes (40 pieces), 12 volt battery (2 pieces), electrode cable (4 rolls), laptop equipped with IP2WIN software, hammer (3 pieces), Portable GPS navigation type, meter (2 pieces), battery charger and stationery. The variables used in this study include independent variables consisting of electric current (I), potential difference (ΔV), electrode spacing. Next, the dependent variable consists of the apparent resistivity value (ρa) and the last additional variable consists of the geology of the research location and the weather.

The data obtained from the field will be calculated using a formula to get the resistivity value using Ms. Excel so that the data can be plotted into the software IPI2WIN. Furthermore, data acquisition is carried out, with data acquisition covering the implementation of data collection activities in the field, in this case using a geoelectric tool to obtain the value of the current injection (I) and the value of the voltage (V), the current and voltage injection value data are then processed to obtain the resistivity value which is then processed. reprocessed using RES2DINV software to get a 2D cross-sectional model (Jamaluddin & Umar, 2018). This software works based on the inversion technique related to the last square method (Pratiwi et al., 2019). RES2DINV is an exact algorithm which is considered good for inversion of 2D resistivity data, and there is good scientific literature where the RMS of 2D electrical imaging is greater than 10% (Satriani et al., 2012). The data processed using this application will produce resistivity values according to conditions in the field by interpreting the data and images according to the depth, thickness and altitude in the field. Subsequent processing is carried out using SURFER so as to produce a correlation between the three tracks so as to produce a map of the distribution of seawater intrusion from Track I to Track III.

The type of material can be determined based on the resistivity value obtained during field research because each material has different resistivity and absorption capacity. Previous research conducted by Telford, 1990 resulted in resistivity values for several materials including the resistivity value of seawater so that it can see the spread of seawater intrusion in Medan Belawan. This aims to provide certainty to researchers and readers in determining the type of material contained in the subsurface layer. The table of resistivity values by Telford, 1976 can be seen in Table 1.

Measurement of the resistivity value was carried out in 3 (three) tracks / stretches in the District of Medan Belawan with a track length of 150-200 meters. The configuration used is Schlumberger using a Neoresist geoelectric device.

The data obtained in the field will be processed using IPI2WIN to obtain the resistivity value of each layer, the depth of each layer and the thickness of each layer identified in the soil. Furthermore, data processing is carried out using SURFER to produce 2D images and produce correlations between the three paths that have been tested in the field. This research was conducted to assist the community in taking groundwater that is suitable for consumption and does not contain seawater. The objectives of this research are:

1. Identify the resistivity value (resistance type) of the soil layer indicated by seawater intrusion using the Resistivity Method (Parinata,2015).
2. Identifying the spread of seawater intrusion on the Belawan Coast using the 2D Resistivity Method.
3. Identification of the alleged distance of seawater intrusion based on data obtained at Belawan Beach using 2D Resistivity Method, as shown Figure 4.

Table 1. Resistivity Value

Jenis Material	Resistivitas (Ωm)
Sea Water (Air Laut)	0,2
Ground Water (Air Tanah)	0,5 – 150
Clay (Lempung)	1 – 100
Sand (Pasir)	1 – 1000
Alluvium (Aluvium)	10 – 800
Gravel (Kerikil)	200 – 8000
Sandstone (Batu Pasir)	50 – 1 x 10^7
Limestones (Gamping)	500 – 10.000
Granite (Granit)	200 – 10^5
Sand and Kerikil yang terendam air laut	0,5 – 5
Sand and Kerikil yang terendam air tawar	50 – 5 x 10^2
Rock Salt (Batuan Garam)	30 – 1 x 10^{13}
Quarzt (Kwarsa)	4 x 10^{10} – 2 x 10^{14}

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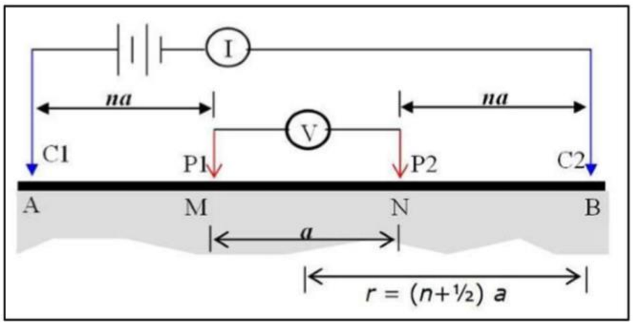

Figure 5. Configuration Electrode Schlumberger

Based on the configuration arrangement, the value will be obtained:

A-B = Current Electrode (m)
M-N = Potential Electrode (m)
a = Distance (m)

After obtaining this value, the value can be determined as follows:

K = Konstanta
I = Electric Current (mA atau A)
V = Potential difference (mV atau V)
ρa = Resistivity (Ωm)

The following is the formula used to determine the value of the constant and the resistivity value obtained.

$$K= \frac{2\pi}{\left[\left(\frac{1}{AM}-\frac{1}{BM}\right)\right]-\left[\left(\frac{1}{AN}-\frac{1}{BN}\right)\right]}$$

with, AM = BM = AN = BN = MN = a
or, K = 2 π a

Based on this, the value of ρa will be obtained with the following:

$$\rho a = K\,\frac{\Delta V}{I}$$

Description:

ρa = Resistivity (Ωm)
K = Konstanta
I = Electric Current (mA atau A)
ΔV = Potential difference (mV atau V)

3. RESULTS AND DISCUSSION

The interpretation results obtained using the IPI2WIN software are as follows. The geoelectric method used in this research resulted 2D section of the lower resistivity surface. 2D cross-section of this resistivity is a representation of the resistivity distribution rock beneath the surface. Closure form resistivity contours in 2D cross-section does not show the dimensions of the rock in below the surface. 2D cross-section of prisoners subsurface types can provide description of the type and characteristics of the coating rock. Areas that have Indications of contamination by seawater are found in the following analysis results (Figure 6).

3.1. Track I

Track I located close to the coast with a distance of 300 meters from the beach. This location is very helpful to see the intrusion of sea water that enters the mainland. In this location also found many industries that can have an impact from the factory on the entry of sea water into ground water.

In path I, it can be seen several layers contained in the soil. The layers that have been interpreted and adapted to the Telford, 1990 are as follows.

Track 1 is close to the beach with a distance of 300 meters from the beach. Based on previous research and data that has been processed using IPI2WIN and SURFER, it was found that in the first layer with a depth of 0 – 1,1 meters, alluvium was found consisting of clay, fine sand, sand, and gravel with a thickness of 1,1 meters. In the second layer, clay with a thickness of 0,539 meters was found at a depth of 1,2 meters – 1,64 meters. Furthermore, in the third layer, sand with a thickness of 1,83 meters was found at a depth of 1,65 meters – 3,47 meters. In the fourth layer, clay with a thickness of 1,67 meters was found at a depth of 3,48 meters – 5,14 meters. In the fifth layer, alluvium was found with a thickness of 7,8 meters at a depth of 5,15 meters – 12,9 meters. In the sixth layer, clay with a thickness of 6,1 meters was found at a depth of 13 meters – 19 meters. The seventh layer with a thickness of 16,4 meters at a depth of 19,1 meters – 35,4 meters has a resistivity value of 0,198 Ωm with the type of sand layer in it containing seawater. In the last layer based on the resistivity value of 4,12 Ωm in the 1960 Telford table, a layer of sand and gravel was found submerged in seawater at a depth of 35,5 meters – 56,9 meters.

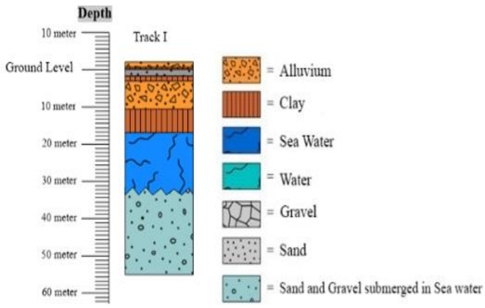

Figure 6. Vertical Cross-Section of the One Track

Table 2. Resistivity Value and Material Type

Layer	Resistivitas (*Telford, 1960*)	Resistance In The Field	Material Type
I	10 – 800 Ωm	16 Ωm	Alluvium
II	1 – 100 Ωm	3,74 Ωm	Clay
III	1 – 1000 Ωm	21,6 Ωm	Sand
IV	1 – 100 Ωm	1,12 Ωm	Clay
V	10 – 800 Ωm	10,1 Ωm	Alluvium
VI	1 – 100 Ωm	1,49 Ωm	Clay
VII	0,2 Ωm	0,198 Ωm	Sea water
VIII	0,5 – 5 Ωm	4,12 Ωm	Sand and gravel with seawater

Data sources are processed from the results TIM.

3.2. Track II

Track II 630 meters from the beach and is a residential area in Medan Belawan District. This location is very suitable to be used as a track location as comparison data with Track I which has a distance of approximately 2,000 meters from Track II. At this location, you can see the impact of community activities on the spread of sea water intrusion in Medan Belawan District.

In track II it can be seen several layers contained in the soil. The layers that have been interpreted and adjusted according to the Telford et al (1990) are as follows.

Table 3. Measurement Results

N	ρ	h	d	Alt
1	6.27	1.3	1.3	-1.3
2	30.4	1.1	2.4	-2.4
3	1.4	3.75	6.15	-6.15
4	23.8	2.5	8.65	-8.65
5	2.55	11.7	20.4	-20.38
6	0.0584	17.7	38.1	-38.06
7	0.793	11.4	49.4	-49.43
8	3.54	22.7	72.1	-72.12
9	0.119			

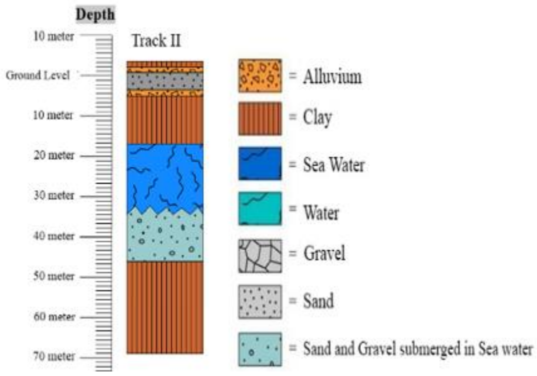

Figure 7. Vertical Cross-Section of the Second Track

Table 3. Resistivity Value and Material Type

Layer	Resistivitas (*Telford, 1960*)	Resistance in the Field	Material Type
I	1 – 100 Ωm	6,27 Ωm	Clay
II	10 – 800 Ωm	30,4 Ωm	Alluvium
III	1 – 1000 Ωm	1,4 Ωm	Sand
IV	10 – 800 Ωm	23,8 Ωm	Alluvium
V	1 – 100 Ωm	2,55 Ωm	Clay
VI	0,2 Ωm	0,0584 Ωm	Seawater
VII	0,5 – 5 Ωm	0,793 Ωm	Sand and Gravel with seawater
VIII	1 – 100 Ωm	3,54 Ωm	Clay

Data sources are processed from the results TIM

Based on the Table 3, it can be seen that in the first layer clay is found with a resistivity value of 6,27 Ωm at a layer thickness of 1,3 meters with a depth of 0 – 1s,3 meters (Table 3). In the second layer, alluvium was found with a resistivity value of 30,4 Ωm at a layer thickness of 1,1 meters with a depth of 1,4 meters – 2,4 meters. In the third layer found sand with a resistivity value of 1,4 Ωm at a thickness of 3,75 meters with a depth of 2,5 meters – 6,15 meters. The reason for the low resistivity value of sand is that the absorption capacity of sand is greater than that of rock or clay in the soil (Simbolon,2016). In the fourth layer, alluvium was found with a resistivity value of 23,8 Ωm with a thickness of 2,5 meters at a depth of 6,16 meters – 8,65 meters. In the fifth layer found clay with a resistivity value of 2,55 m at a thickness of 11,7 meters with a depth of 8,66 meters – 20,4 meters. In the sixth layer, seawater intrusion was found with a resistivity value of 0,0584 Ωm at a thickness of 17,7 meters with a depth of 20,5 meters – 38,1 meters. In the seventh layer found sand and gravel submerged in seawater with a resistivity value of 0,793 Ωm with a thickness of 11,4 meters at a depth of 38,2 meters – 49,4 meters this is because seawater absorbs in the seventh layer. The last layer is clay with a resistivity value of 3,54 Ωm with a thickness of 22,7 meters at a depth of 49,4 meters – 72,1 meters. Clay has a characteristic resistivity value low, but when the clay is contaminated by sea water the resistivity value of the clay will be lower than normal (Astutik et al., 2016). Areas that have Indications of contamination by seawater are found in the following analysis results:

3.3. Track III

Track III is at the end of the Medan Belawan. District with a distance to Track II of approximately 2.000 meters and a distance to Track I of approximately 4,000 meters. (Figure 8)

The distance of Track III with the shoreline is 1,200 meters. This location was chosen as the comparison data between Track I and Track II.

In track III, it can be seen several layers contained in the soil. The layers that have been adjusted according to the Telford et al, 1990 are as follows in Table 5.

Table 4. Measurement Results

N	ρ	h	d	Alt
1	10.8	0.689	0.689	-0.6895
2	3.94	2.72	3.41	-3.412
3	18.9	1.53	4.94	-4.943
4	8.65	1.12	6.07	-6.066
5	1.17	6.62	12.7	-12.69
6	56.5	2.82	15.5	-15.51
7	10.3	4.05	19.6	-19.55
8	0.0035	23.9	43.4	-43.43
9	1.35	24.5	68	-67.97
10	2.59			

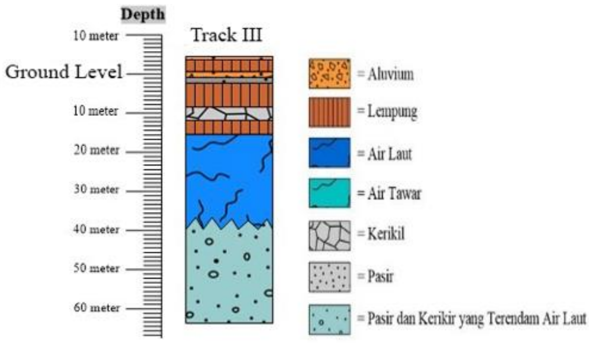

Figure 8. Vertical Cross-Section of the Three Track

Table 5. Resistivity Value and Material Type

Layer	Resistivitas (*Telford, 1960*)	Resistance in the Field	Material Type
I	10 – 800 Ωm	10,8 Ωm	Alluvium
II	1 – 100 Ωm	3,94 Ωm	Clay
III	10 – 800 Ωm	18,9 Ωm	Alluvium
IV	1 – 1000 Ωm	8,65 Ωm	Sand
V	1 – 100 Ωm	1,17 Ωm	Clay
VI	200 – 8000 Ωm	56,5 Ωm	Gravel
VII	1 – 100 Ωm	10,3 Ωm	Clay
VIII	0,2 Ωm	0,0035 Ωm	Seawater
XI	0,5 – 5 Ωm	1,35 Ωm	Sand and Gravel with Seawater

Data sources are processed from the results TIM

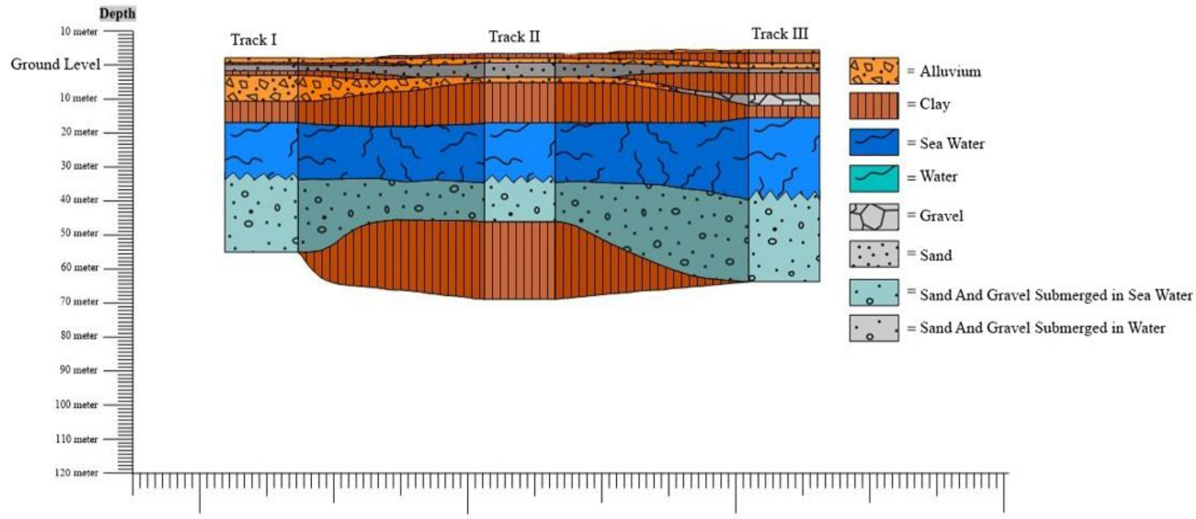

Figure 9. 2D Cross-Section Model

In track III, several materials can be identified in the soil according to the table associated with the Telford resistivity (Table 5) , Telford et al, 1990. The material contained in the soil and has been adapted to the geological map, namely in the first layer is alluvium with a thickness of 0,689 meters with a depth of 0 – 0,689 meters. In the second layer there is clay with a thickness of 2,72 meters at a depth of 0,69 meters – 3,41 meters. In the third layer, alluvium with a thickness of 1,53 meters was found at a depth of 3,42 meters – 4,94 meters. In the fourth layer there is sand with a thickness of 1,12 meters at a depth of 4,95 meters – 6,07 meters. The fifth layer is clay at a thickness of 6,62 meters with a depth of 6,08 meters – 12,7 meters. Furthermore, what was identified in the sixth layer was gravel with a thickness of 2,82 meters at a depth of 12,8 meters – 15,5 meters. In the seventh layer, clay with a thickness of 4,05 meters was found at a depth of 15,6 meters – 19,6 meters. Then in the eighth layer, seawater intrusion was found with a thickness of 23,9 meters at a depth of 19,7 meters – 43,4 meters with a resistivity value of 0,0035 Ωm. On the last track, sand and gravel were found submerged in seawater with a resistivity value of 1,35 Ωm at a thickness of 24,5 meters and a depth of 43,5 meters – 68 meters (Table 4).

3.4. Sectional Model in 2D Form from Geoelectrical Measurement

Since resistivity is sensitive to fluids and conductive minerals (Telford et al., 1990), groundwater polluted by seawater will experience a decrease in the resistivity value. This causes differences in the resistivity value of contaminated and unpolluted groundwater (Nisa & Yulianto, 2012;Muslim2021). Moreover, the land surface conditions and topography in the surrounding Belawan area are quite close to the sea. The level is almost the same or at least close to the sea level, this will accelerate seawater intruding into the surrounding groundwater. Based on the correlation, there are layers that are connected to each other. The correlation results also found a layer of groundwater and a layer of water containing salt. The following is a 2D cross-sectional model from the measurements of the three tracks in Medan Belawan District.

In Figure 9, it can be seen that sea water has entered the material below the ground surface, so there are indications of salt water contamination as follows:

On Route I with an elevation of 3 meters at a depth of 19.1 – 35.4 meters, seawater intrusion was found with a resistivity value of 0.198 m (according to Table 2 Resistivity Values), blue in clay sandstone.

On Route II with a height of 4 meters, sea water intrusion was found at a depth of 20.5 meters - 38.1 meters. The resistivity value on Track II is 0.0584 m (according to Table 2 Resistivity Values).

On Line III with a height of 5 meters, sea water intrusion was found at a depth of 19.7 meters – 43.4 meters, which is indicated by a relatively small resistivity value of 0.0035 m (according to Table 2 Resistivity Values)..

4. CONCLUSION

The results of research conducted using the Schlumberger Configuration 2D Resistivity Method in identifying sea water intrusion in the Belawan area. Geoelectric method survey results to assess subsurface geological formations, aquifer geometry and seawater intrusion, generally have sand formations, clay at shallow depths, most of which are indicated water intrusion into the aquifer below. The distribution of seawater intrusion indications leads to the coast generally trending southwest to northeast.

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