ISSN 2541-223X
Volume 4 2022

BRACKISH WATER MAPPING BASED ON WATER QUALITY DATA AND GEOELECTRICAL SURVEY : CASE STUDY IN THE SHALLOW GROUNDWATER OF TEGAL CITY

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ABSTRACT

Salty water in the aquifer influences changes in groundwater quality may cause by pumping activities and/or natural phenomena. This paper reported the result of salty water mapping in the shallow groundwater of Tegal city. The EC values of groundwater in the study area ranges between 510 µS/cm to 7610 µS/cm, and TDS values are between 300 mg/L to 2450 mg/L. The geoelectrical measurement on study area reveals a very low resistivity layer of 0.307 ʌm at a depth of 2.87 to 12 meters, indicating brackish water. Based on the EC and TDS also geoelectrical survey, a map of salty water is produced and shows that in shallow groundwater of Tegal City, brackish water appears in the middle part of City and northeast part near the coastal area.

Keywords : Water mapping; Water Quality Data; Geoelectrical

1. INTRODUCTION

Groundwater is a crucial resource for society as well as for sustaining ecosystems. Globally, many cities depend on groundwater to fulfill their water needs. The rapid development of infrastructure for the cities in the coastal areas of Northern Java has a positive side in terms of the economic growth of a region, including Tegal City and its surroundings. The coastal areas are popular places to live and do business because they have good weather, a lot of mineral resources, accessible transportation, chances for maritime trade, and cultural or recreational activities (J. E. Neumann *et al,* 2015). The groundwater is affected by ocean phenomena such as tides, storm surges, tsunamis, and saltwater seepage. The entry of seawater into freshwater aquifers causes infiltration. The delicate hydrogeological balance between freshwater and seawater in coastal aquifers is being disrupted due to significant groundwater extraction (W. Wilopo *et al,* 2018). It is an outcome of the growing urbanization of the coastal area (Akinlalu and Afolabi, 2018). Seawater intrusion impacts the local community's health and economic and socio-cultural developments in the coastal areas (Prusty and Farooq, 2020).

Geologically, the coastal area is an alluvial deposit consisting of gravel, sand, silt, and clay resulting from the transportation and erosion of rocks in the upper river. Aquifers with good water qualities in coastal plains are generally confined aquifers. Confined aquifers contain a confining layer so that the water quality is relatively unaffected by activities on the surface. Still, unconfined aquifers can also be a good source of groundwater, especially in coastal embankment areas.

The main problem in coastal areas is the diversity of the aquifer system and the position and distribution of seawater intrusion/intrusion both naturally and artificially due to

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DOI: https://doi.org/10.20885/icsbe.vol2.art9

excessive groundwater extraction for household, fishing, tourism, and industrial needs. The groundwater abstraction results in a decrease in the fresh groundwater level and can trigger the infiltration of seawater towards the mainland (Sahana and Waspodo, 2020). Over-pumping can lead to an upcoming that permits saltwater intrusion from the bottom of the well. Over-pumping can lead to localized saltwater intrusion (Jasecko *et al,* 2020). The phenomenon of seawater intrusion in Tegal City will impact the communities. For that reason, research on the impact of seawater intrusion in Tegal City is to find out how much seawater intrusion has existed. The objective of this study was to investigate seawater intrusion based on the relationship between electrical conductivity (EC), total dissolved solids (TDS), and Geoelectrical data to know the depth of seawater intrusion.

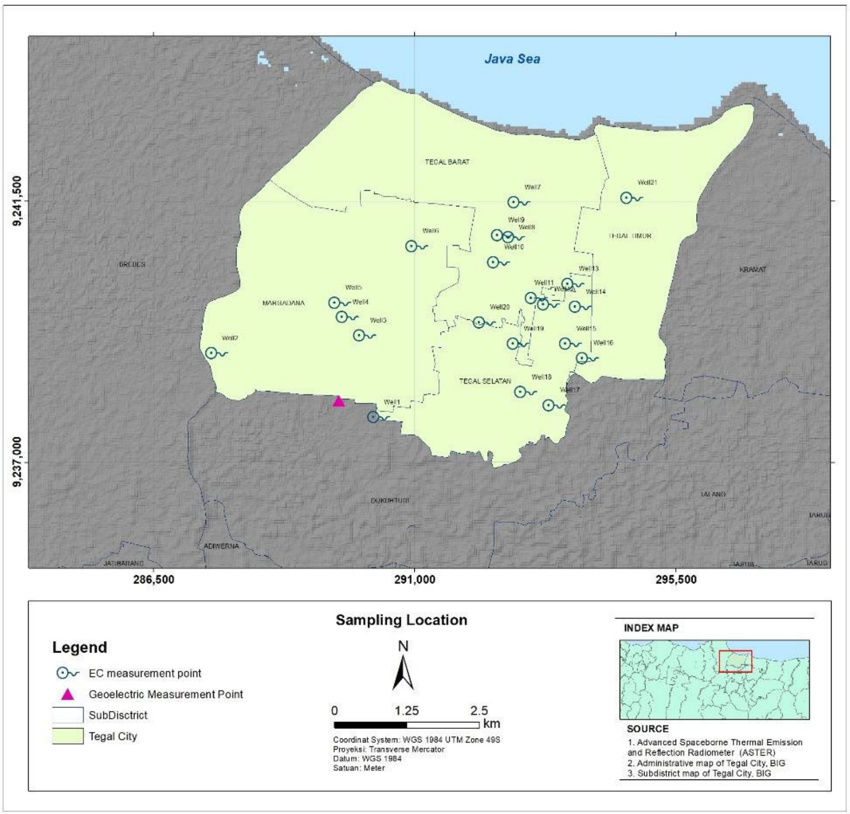


Figure 1. Groundwater observation points and geolectrical measurement point.

2. METHODOLOGY

This research was conducted in Tegal City in four districts, including Margadana, Tegal Timur, Tegal Barat, and Tegal Selatan. The primary data was collected from the 21 unconfined groundwater well samples around Tegal City. The distribution of sampling points is shown in Figure 1.

Under natural conditions, fresh groundwater in unconfined and confined aquifers is released and flows toward the sea. The increasing amount of groundwater abstraction results in a backflow of seawater into the freshwater aquifer system called seawater intrusion (Santoso dkk, 2013).

The interface or boundary of freshwater and seawater that occurs due to differences in the specific gravity of those saline and fresh water is through diffusion. The shape and movement of the boundary are affected by the hydrodynamic balance of freshwater and seawater. If there is a situation where the seawater has been below the aquifer, the seawater will immediately penetrate the well. Similarly, seawater intrusion enters the aquifer slowly through the coast if the aquifer lacks freshwater. This situation is known as Herzberg's Law (L. Todd *et al,* 2001).

According to the Ghyben-Herzberg concept, the interface of seawater and freshwater is found at a depth of 40 times the groundwater level above sea level. This phenomenon is caused by the difference in density between seawater (1.025 g/cm^3) and freshwater (1.025 g/cm^3).

$$Z = \frac{pf}{ps-pf} hf \tag{1}$$

We can define the value of $Z = 40\ hf$ from equation 1,
whereas:

Z = depth of interface water and saline water (m)
hf = water level (m)
ps = seawater density (g/cm^3)
pf = freshwater density (g/cm^3)

Seawater has greater specific gravity than fresh water. As a result, seawater will quickly intrude groundwater. As a result of groundwater's higher piezometric pressure than seawater, which prevents seawater from penetrating deeper, an interface is formed as a boundary between groundwater and seawater as a natural barrier between the two forms. (M. Gusman *et al,* 2020)

The data were analyzed based on electrical conductivity (EC) values and total dissolved solids (TDS). The definition of electrical conductivity is based on Indonesian National Standard (SNI) number 6869.1 about Test Method for Electrical Conductivity (EC) which is the ability of water to conduct electric current and expressed in mhos/cm (µS/cm). The electrical conductivity or conductivity of water depends on the concentration of chloride ions, water temperature, and dissolved solids. Therefore, the increase in EC will increase the TDS value and vice versa. The classification of groundwater quality parameters is based on the 1986 ad Hoc Sea Water Intrusion (PAHIAA) Committee Decree.

Table 1. Classification of groundwater salinity (PAHIAA, 1986).

No	Water Quality	TDS (mg/L)	EC (µS/cm)
1	Freshwater	<1,000	<1,500
2	Rather Brackish	1,000 – 3,000	1,500 – 5,000
3	Brackish	3,000 – 10,000	5,000 – 15,000
4	Salty	10,000 – 35,000	15,000 – 50,000
5	Brine	>35,000	>50,000

Margadana Subdistrict as shown in Figure 1. The principle of the technique is to inject the electric current (I in Ampere units) into the ground (soil) and observe the potential difference (V in Volt units) at given points by using stainless steel electrodes. A different electrode distance space configuration obtains the variation of resistivities of the subsurface layer. The value of the measured potential difference depends on the physical properties of the rock (D. Setono *et al,* 2014, such as porosity, salinity, and fluid or clay content. Therefore, the method is applied to estimate subsurface geological conditions based on the resistivity distribution of the medium, both laterally and vertically.

In the case of a half-space isotropic homogeneous medium, as illustrated in Figure 2, the measured resistivity is the actual resistivity of the medium (Telford an Sheriff, 1991). However, in reality, the earth consists of layers with resistivity variations both laterally and vertically, so these layers influence the measured potential. The measured resistivity value is not the actual resistivity value and is defined as apparent resistivity. The measurement results contain information about the resistivity near the surface (shallow) for the relatively close distance between the current and potential electrodes. On the other hand, the wider the electrode distance, the more information obtained to describe conditions at great depths

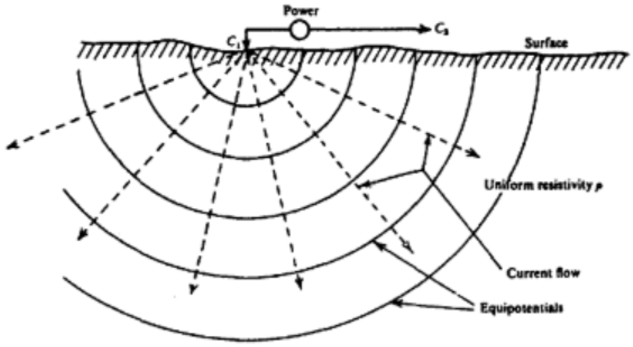


Figure 2. Electric current flow on a homogenous medium (Telford, 1990).

Several electrode configurations are applied in the geoelectrical data measurement: Wenner, Pole-pole, Schlumberger, Dipole-dipole, and Pole-dipole electrode configurations. Specific electrode configuration is applied to estimate the lateral or vertical variation in resistivity values. We are using the Schlumberger electrode configuration to determine the vertical resistivity of rock or soil layers. This configuration is known as 1-dimensional (1-D) geoelectrical measurements or Vertical Electrical Sounding (VES).
The results of geoelectrical measurements of VES are variations in resistivity values which are modeled by using a curve fitting technique, so the true resistivity of the layer is obtained vertically. The measurement data for each datum or measurement point consists of injected electric current (mA), potential difference (mV), and resistivity value (∧m). Geoelectrical data measurement is suited for shallow investigation, such as delineating a groundwater potential or bedrock geometry configuration

3. RESULT AND DISCUSSION

The result of groundwater quality data measured showed that the highest concentration of TDS and EC were 7610 µS/cm and 2450 mg/L in the Tegal Barat District (see Figures 3 and 4). Based on the PAHIAA classification, the result of TDS and EC in this area were categorized as freshwater, rather brackish, and brackish. The TDS chart of Tegal City showed two categories: freshwater and rather brackish. The lowest TDS was recorded in Well 17 at Tegal Selatan District with a 300 mg/L value. The TDS concentration value collected from 18 dug wells was below 1000 mg/L; others from 3 dug wells are higher than 1500 mg/L in Tegal Barat and Margadana District.

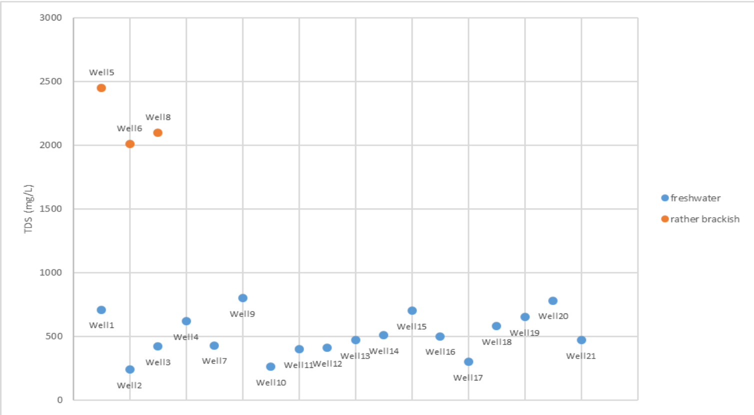


Figure 3. Total Dissolved Solid (TDS) distribution chart of Tegal City.

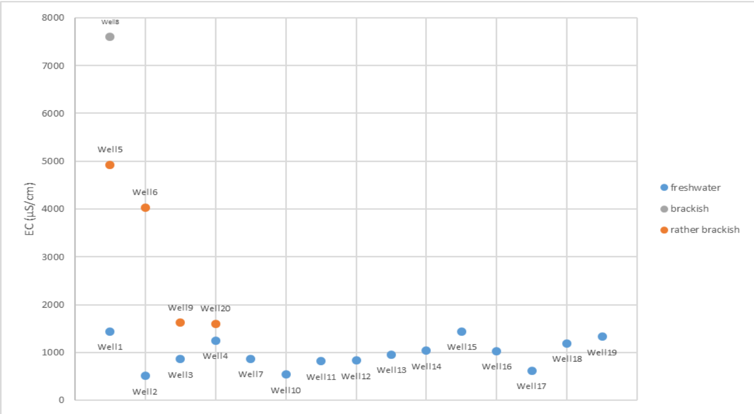


Figure 4. Electrical Conductivity (EC) distribution chart of Tegal City.

EC table of Tegal City shows three classifications: freshwater, rather brackish, and brackish. The lowest EC concentration was recorded in Margadana District with a value of 510 µS/cm (Figure 5). The EC concentration value from 15 dug wells below 1500 µS/cm is classified as freshwater. EC values were recorded higher than 5000 µS/cm in one dug well located in Tegal Barat, classified as brackish.

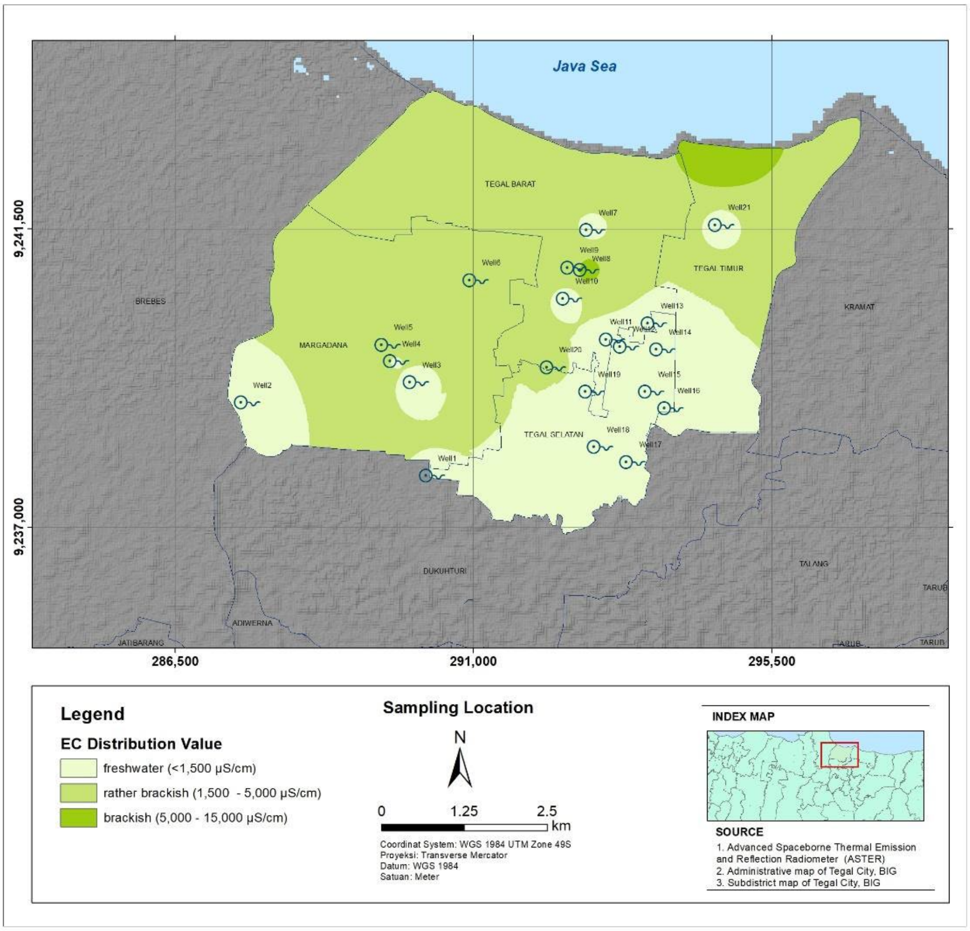


Figure 5. Electrical Conductivity (EC) Map of Tegal City

Additionally, the study measures the static water level, temperature, and pH. Using these data, the equation can determine the sea-freshwater interface (Table 1). Given that the interface between seawater and freshwater is found at a depth of 56 meters in well 11, it can be inferred that groundwater pumping is prohibited below this depth and that governmental regulations limit the rate of pumping not to exceed the recommended flow rate. This is done to stop the seawater intrusion from rising further. To prevent seawater intrusion, the well's maximum depth should be lower than the depth of the contact. Additionally, the pumping rate should be restricted so that it is lower than the aquifer's groundwater outflow.

Table 2 The position of the sea-freshwater interface.

Number	Location	Easting (X)	Northing (Y)	SWL (m)	pH	Temperature (°C)	Sea-Freshwater Interface (m)
1	Well1	290371	9237779	0.3	7.1	27.9	12
2	Well2	287579	9238881	1	7.1	28.1	40
3	Well3	290132	9239188	0.7	6.8	27.9	28
4	Well4	289829	9239505	1	8.2	28.6	40
5	Well5	289705	9239753	0.2	6.9	28.5	8
6	Well6	291030	9240730	0.1	7.4	29.5	4

Number	Location	Easting (X)	Northing (Y)	SWL (m)	pH	Temperature (°C)	Sea-Freshwater Interface (m)
7	Well7	292793	9241483	0.35	7	29.6	14
8	Well8	292694	9240881	0.4	6.9	29.6	16
9	Well9	292511	9240919	0.4	6.9	29.1	16
10	Well10	292440	9240451	0.5	7	29	20
11	Well11	293087	9239834	1.4	6.5	29.5	56
12	Well12	293300	9239724	0.5	7	30.1	20
13	Well13	293721	9240079	1	7.3	30.7	40
14	Well14	293846	9239683	1	7.2	30.1	40
15	Well15	293682	9239044	0.6	6.7	29.7	24
16	Well16	293973	9238796	0.7	6.9	29.2	28
17	Well17	293397	9237985	0.9	6.5	29.4	36
18	Well18	292910	9238213	0.3	6.7	28.9	12
19	Well19	292775	9239046	0.45	6.9	28.4	18
20	Well20	292194	9239413	0.5	5.8	28.8	20
21	Well21	294740	9241563	0.45	7	28.8	18

Using the water level values, the Surfer program was used to assess the pattern and flow direction of the seawater intrusion dispersion. To ascertain the distribution and flow direction, contour tools were used to merge the information with grid vector map tools. The dispersion pattern and flow direction were affected by the size and distance of the observed parameter value. According to Figure 6's groundwater flow pattern and direction in Tegal City, the groundwater in the research area typically flows from south to north

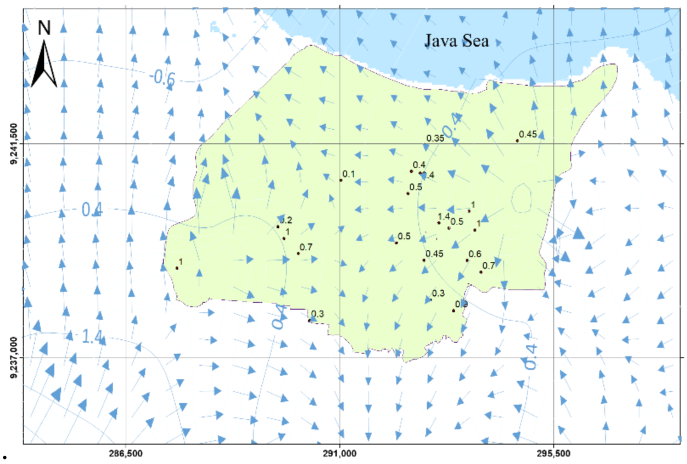
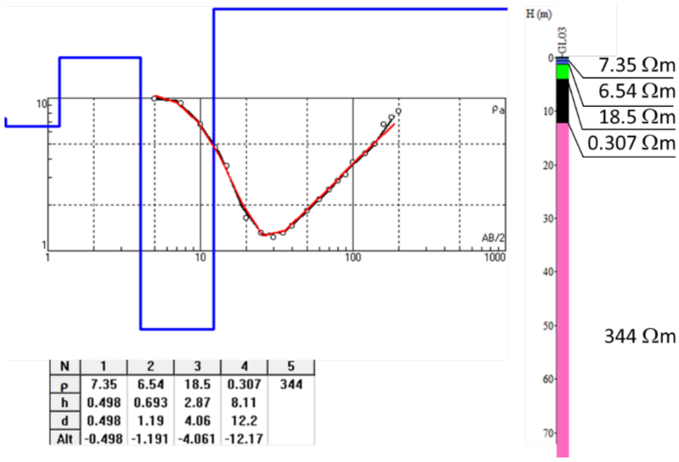


Figure 6. Pattern and flow direction contour of groundwater in Tegal City (administrative map, BIG, 2019).



N	1	2	3	4	5
ρ	7.35	6.54	18.5	0.307	344
h	0.498	0.693	2.87	8.11	
d	0.498	1.19	4.06	12.2	
Alt	-0.498	-1.191	-4.061	-12.17	

Figure 7 Resistivity model based on Geoelectrical VES data.

The VES geoelectrical measurement data shows the range of apparent resistivity value is 0.307 ∧m to 18.5 ∧m as shown by the black hollow circle symbol in Figure 7. True resistivity model based on Geoelectrical VES data above. The resistivity model results show the distribution of resistivity vertically, varying from a slightly conductive value of 7.35 ∧m from surface to 0.5 meters in depth, followed by an intermediate value of 6.54 ∧m with a thickness of 0.67 meters. A very low resistivity or very conductive layer of 0.307 ∧m was identified at a depth of 2.87 meters with a thickness of about 5 meters. The highly resistive layer with a value of 344 ∧m starting at a depth of 12 meters and below is a homogeneous medium layer that may contain more fresh water.
According to Table 2, the low resistivity zone near the Well 1 sampling location is located at a distance of about 12 meters, similar to the distance between the sea and freshwater interface in Well 1. It is interpreted that the aquifer may contain brackish water.

4. CONCLUSION

Based on the findings of the investigation using EC, DHL, and a geoelectrical model in Tegal City, it can be said that the study area's EC values range from 510 µS/cm to 7610 µS/cm , and its TDS values range from 300 mg/L to 2450 mg/L, and a very low resistivity layer measuring 0.307 ∧m was found at a depth between 2.87 until 12 meters, indicating intrusion of seawater may already intrudes freshwater due to groundwater pumping especially in the northeast part and middle-part of Tegal City.

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