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RESEARCH ARTICLE

Groundwater resources mapping for small island using Geoelectrical Technique

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Abstract The measurement of 2D geo-electrical using Wenner Alpha configuration was conducted in the shore line of northern part of Ternate island, in order to know the depth of interface and to analyze the aquifers in conjunction with estimation of ground water potential. Water quality analysis is also conducted in some dug wells, such as in situ water temperature, electrical conductivity, pH, turbidity, dissolved oxygen, and salinity. Due to laboratory analysis, the values of measured parameters of water quality from some dug wells meets to the standards referred, especially for drinking water. The result of interpretation from geo-electrical data showed the depth of interface less than 10m. From a drilled well data near shore line, indicate about 5m deep of interface. Base on geo-electrical survey, water quality analysis and field observation can be concluded that Ternate Island has limited potential of ground water, especially related to amount of fresh ground water. Which are now days, no alternative source yet of clean water for domestic use.

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1.Introduction

Groundwater is a renewable natural resource and widely used for drinking water. The potential of groundwater can be estimated in many ways. One of the most common is by investigating the characteristic of aquifer using geo-electrical survey (Kontar and Ozorovich, 2006; Dikedi, 2012; Kudamnya and Osumeje, 2015). The demand of this scarce resource has increased due to the population growth. However, groundwater is not only a valuable resource for water supply, but also a vital component of the global water cycle and the environment. In 2010 the population of Ternate island estimated to be 181.000 inhabitant, and projected to increase 2.53% each year (BPS Provinsi Maluku Utara, 2018). Most people in this area use ground water as a source for domestic water needs. In coastal areas, fresh water drawn from shallow ground water. Most shallow groundwater in coastal areas susceptible to contamination. To determine the quality of groundwater quickly, it can be seen the levels of salinity (Maulana and Sudarmadji, 2016), with simply tasting it.

Naturally the hydraulic gradient of the groundwater table (piezometric head) would allow the freshwater to flow to the sea. Over extraction of groundwater pumping from coastal aquifers caused the seawater would advance further inland causing a significant damage to the aquifer. This will allow for the development of an extensive dispersion zone. In the dispersion zone, the flux of water will be under the hydraulic gradient, while the transport of salt ions will be dominated by advection and hydrodynamic dispersion processes. Due to the density difference between the freshwater and the salt water, a cyclic flow is usually encountered at the seaside boundary, especially where the aquifer depth at the seaside boundary is relatively large (Sherif et al., 2012).

As a small volcanic island, Ternate certainly has limitation in the catchment area, which has implication for the availability of groundwater, especially fresh water. The existence of a volcano in the middle of the island would be the cause of groundwater flow from the height to the edge of the island and the coastal areas of island become groundwater storage. Stratification of volcanic deposit as aquifer layers that send water to the lower ground. The research area lies in north-western of Ternate island (see Fig. 1). This location chosen because the withdrawal of groundwater for domestic use are still limited, compared with other side of the island. It is mean that the groundwater system is in natural condition.

This research aims to reveal the potential of shallow ground water in coastal area which is susceptible to intrusion if over pumped.

2.Methods

Both geo-electrical method and water quality analysis were applied in this research. Geo-electrical method is commonly used in groundwater exploration, mainly due to the close relationship between electrical conductivity and some hydrological parameters.

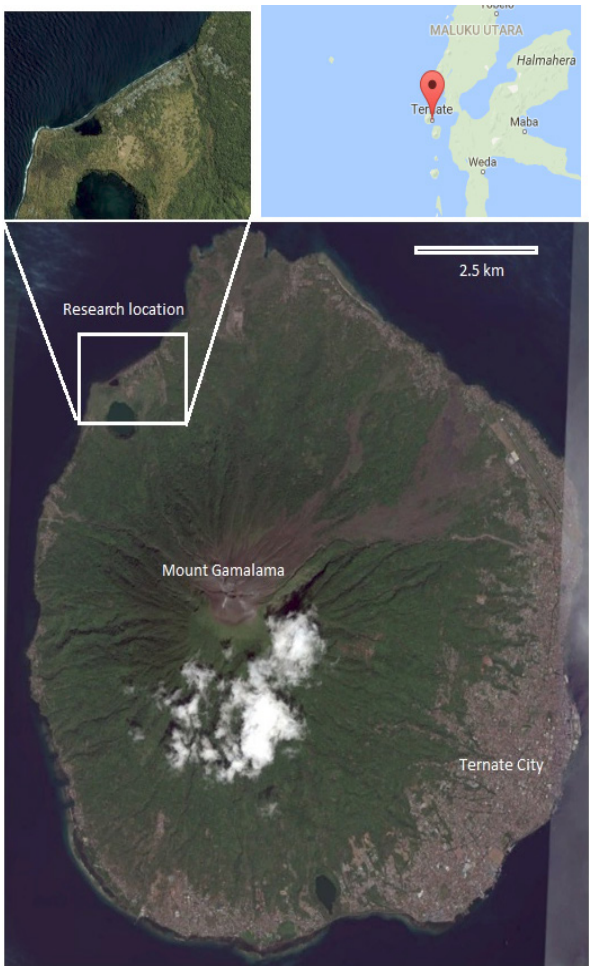

Figure 1. Image map of Ternate Island.

The geo-electrical method is also used for detecting groundwater presence and interface that differentiating freshwater and saline water. Water quality method is used to measure some physical and chemical water properties, such as temperature, pH, conductivity, turbidity, dissolved oxygen, and salinity. A total of 3 dug wells and a drilled well were measured physical and chemical water properties and then compared with interface water.

Hydrogeology and Research Area

Hall and Wilson (2000), identified five main zones (after collision between crust of Australia and Eurasia) namely Neogene Borneo, Neogene of Celebes, Neogene of Banda, Neogene of North Molluca and Neogene of Papua (New Guinea). This tectonic setting creates the array arc island in western Halmahera. Ternate Island with Mount Gamalama is one of the arc islands.

The 1: 25,000 geological maps of Ternate Island established by Bandung Centre of Geology Research (Bronto and Lockwood, 1982), explained that research area is dominated in its upper part by phreatic explosion deposits of Tolire Jaha and Tolire Kecil maars (see Fig. 2). The deposit consists of partly consolidated, unsorted fragmental volcanic materials of various lithologies near

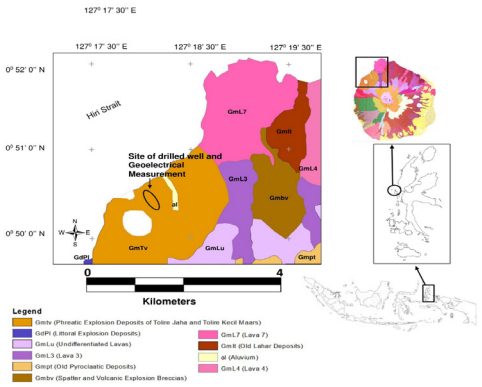

Figure 2. Geological map and site of measurement.

maars, but on the maar flanks consist of well stratified base surge deposits and bombs sag structures, formed in September 1775 (Bronto and Lockwood, 1982).

The research area is located in the coastal area of north-western Ternate island, and influenced by a tropical marine climate and season climate, with an annual precipitation range from 2138 mm - 3693 mm. The average of annual temperature is measured from the meteorological station of Duma Galela, Ternate and Tobelo range from 25.6 oC – 26.1 oC. Therefore, the climate in North Maluku is strongly influenced by the ocean (including water area) and varies between each part of the territory. Rainfall generally occurs not only during the rain season but also in dry season caused of orographic processes.

The research was performed in two stages that included geo-electrical survey, and water quality data of dug wells and drilled well. The descriptions of each methods are given.

Geo-electric Survey

The purpose of geo-electrical survey is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated (Loke, 2004). The 2D survey was carried out with ARES multi electrodes using Wenner-Alpha configuration (see Fig. 3).

The depth of layer investigation is equal to the largest electrode spacing. The survey is usually carried out with a system where the electrodes are arranged along a line with a constant spacing between adjacent electrodes. This research is applied perpendicular to shoreline with 120m total length cable and 5m distance each electrode. The line of 2D resistivity measurement was completed, with maximum 23 m depth. The

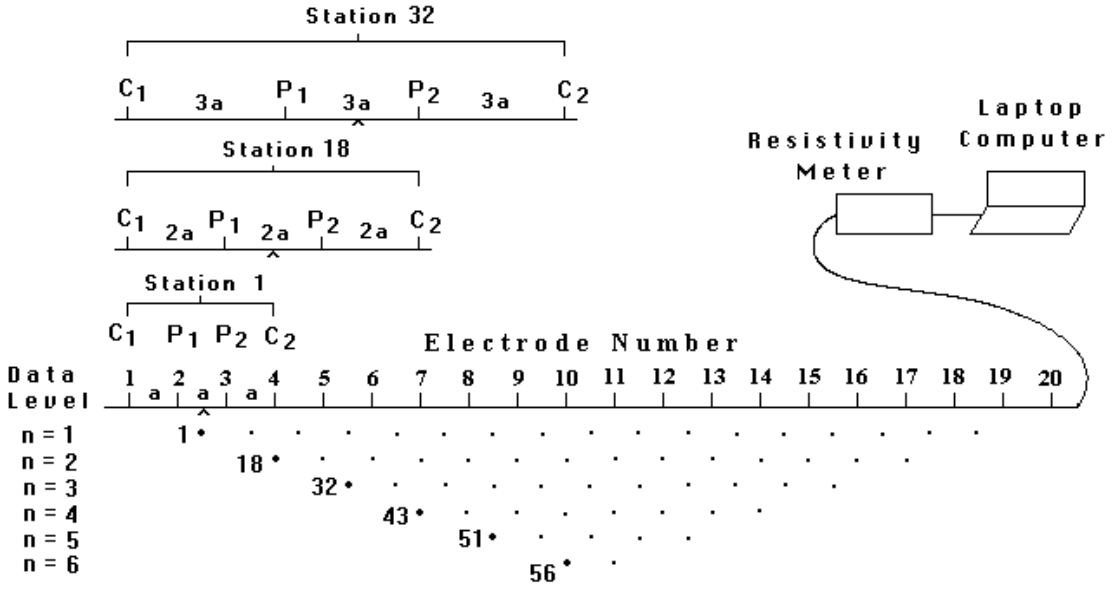

Figure 3. The arrangement of electrodes for a 2-D electrical survey with a Wenner Alpha array and the sequence of measurements used to build up a pseudo section (Loke, 2004).

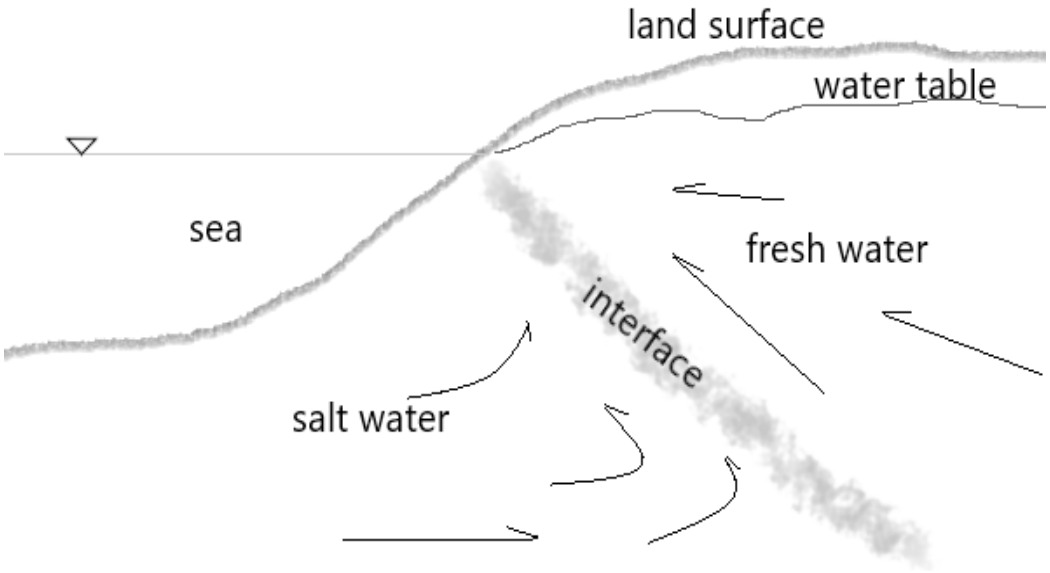

Figure 4. Circulation of freshwater and saline water in a zone of diffusion in a coastal aquifer

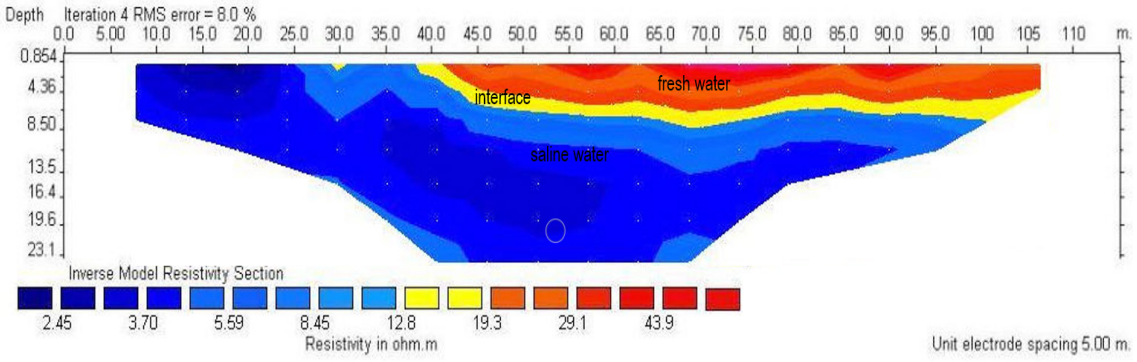

Figure 5. The result of geo-electrical measurement that showed the interface lens.

field data from ARES were analyzed with Res2DInv computer program by Loke (2004).

In-situ water quality measurement

The water quality data were carried out using Horiba instrument. Using this instrument, it is possible to collect direct data, but limited to a certain parameter. Some key parameters measured were temperature, pH, conductivity, DO, turbidity and salinity. When water of low conductivity is polluted, its conductivity increases. For this reason, conductivity is also used as an indicator of pollution in these types of water. The organisms in water live on DO. The level of DO is affected by the water temperature, salt concentration (conductivity), atmospheric pressure, and other conditions, and the saturation level decreases with increases in water temperature. It is known that the saturation level of O2 dissolved in pure water at 25°C and 1 atm (1013 hPa) is 8.11 mg/L. The DO is an indicator of the level of organic pollution in water. For basic water quality investigation, these parameters are sufficient to perform the water quality status. Some detail instruction how to investigate these parameters can be seen in the Horiba manual (Horiba, 2008).

3.Result and Discussion

Construction of Aquifer

According to Fetter (2001), in the coastal area salt water is found adjacent to fresh water in the land area. Fresh groundwater usually grades into saline water with a steady increase in the content of dissolved solids. In some situation, the contact may be quite sharp, that is, a very thin zone of mix water. Fresh water is flowing upward to discharge near the shoreline, and there is a cyclic flow in the salty water near the interface (see Fig. 4).

The result of 2D geo-electrical measurement in the coastal area which perpendicular to shoreline is shown in Figure 5.

Quantitative interpretation data of 2D (mapping) resistivity inversion explained the main features of the derived structure, from the surface to downward (< 9 m depth) saturated by unconfined groundwater as figured on Figure 5. The value of resistivity ranges from 19 – 44 Ωm/cm, considered to be caused by sandy beach and gravel corresponding to fresh water (good quality coastal fresh water). The resistivity value ranges from 2 – 19 Ωm/cm, corresponding to saline water and interface lens.

Another 2D geo-electrical measurement carried out about 250 m landward from shoreline by Achmad et al. (2016), showed that the depth of interface is 15 m below surface (see Fig. 6).

The inverted 2D resistivity value range from 33–130 Ωm, considered to be caused by sand and gravel of varying grain size (fine to medium), corresponding to fresh water (very good quality water). The resistivity value ranges from 0.6 – 11 mS/cm, corresponding to saline water.

Water Quality Data

In order to understand Water Quality Data of dug wells and interface water, we need to direct measure the water at the spot. The water quality data were carried out using Horiba instrument and the parameters of the physicochemical are temperature, conductivity, pH, turbidity, dissolved oxygen, and salinity (see Table 1).

Table 1. Physicochemical data of groundwater.

Parameter	well-#1	well-#2	well-#3	well-#4
Temperature (OC)	26.9	27.24	27.07	28.51
pH	7.1	7.7	7.8	7.6
EC (mS/cm)	0.382	0.493	0.213	6.09
Turbidity (NTU)	0	0	0	6.6
DO (mg/L)	5.69	7.96	10.6	8.5
Salinity (ppt)	0.2	0.2	0.1	3.3
Depth of well (m)	4.4	8.41	2.3	13

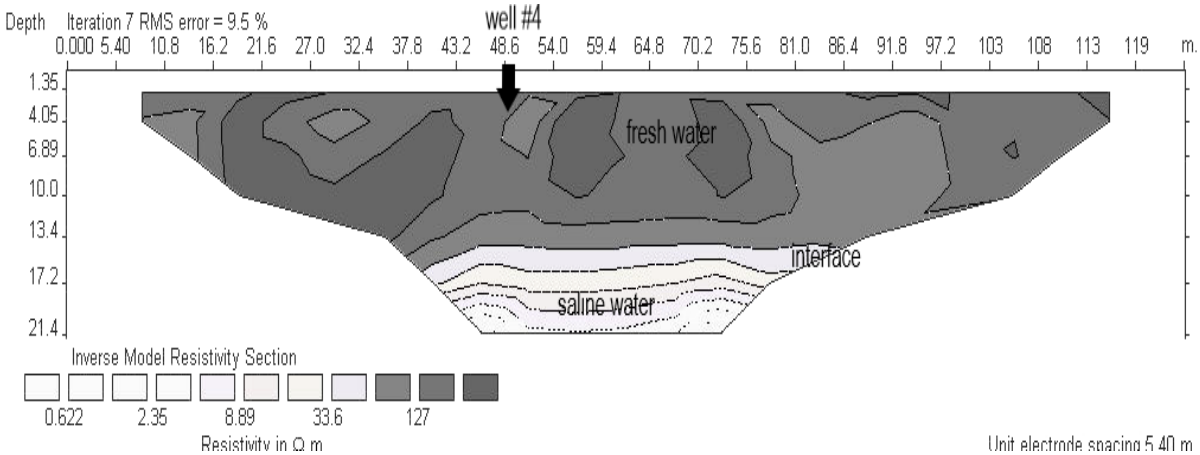

Figure 6. The 2D inverted result of site measurement (Achmad et al., 2016).

All of wells surveyed are located on along coastal area.

Groundwater samples have been collected from 3 dug wells (#1, #2 and #3) and 1 drilled well (#4). The water from well #4 was indicate as interface water, because the depth of well is 13 m (see Table 1). Some of dug wells physico-chemical data that can be distinguished to interface water are:

1) The conductivity value of dug wells water varied from 0.2 to 0.49 mS/cm, indicating nature fresh water. The conductivity value of interface water is 6.09 mS/cm, indicating mixture water between fresh water and sea water. This may cause of high concentration major cations and anions.
2) The turbidity value of dug wells water is absolutely zero. These indicate the clearness of nature fresh water. The turbidity value of interface water is 6.6, can be due to the poor muddy sediments present in the aquifer system which further infers saline intrusion.
3) The salinity value of interface water is higher than dug wells caused of ions and solid dissolved.

Base on geo-electrical survey, the interface can be easily mapped. In this area the thick of fresh water column is < 5 m, it is mean that this area has low potential of ground water. If it is to be correlated with settlement density, it became clear that the risk that people fail getting clean water from this aquifer is severe. Related to field survey conducted in period of 2014-2016. The distribution of settlement in Ternate island mostly lay on lower slope of the volcano. Now days most of the people in this area use ground water for their domestic use.

4.Conclusion

Seawater intrusion is a natural phenomenon in coastal aquifers. Whether we like it or not, it occurs. However, it becomes problematic when man withdraws water close to coastal areas. In this paper, we disclose how geophysical techniques have made, and continue to make, a major contribution to subsurface investigations. This research provides a qualitative assessment of the utility of the resistivity and induced polarization a geophysical technique for resolving lithology. It was found that with careful interpretation, of inverted 2D resistivity imaging can improve understanding the properties of the border between fresh water and saline water. The inverted 2D resistivity showed the depth of interface border, the authors hope this research will help the planers and decision makers to devise the wise way in develop groundwater plans for water resources.

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