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Research Article

Aquifer distribution and groundwater geochemistry in Bojonegoro Sub-district, Bojonegoro District, East Java Province, Indonesia

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Abstract: Bojonegoro Sub-district is the capital of Bojonegoro District, East Java Province, Indonesia. This area has quite high economic growth supported by large oil and gas reserves. An increasing number of population and improving economy will cause more water needs. People in this area use groundwater as their primary source for daily purposes. However, information on the potential of groundwater resources is not yet well available. Therefore, the study aimed to determine groundwater flow patterns, the distribution of aquifers, and groundwater geochemistry. The study was conducted by measuring groundwater level as many as 42 points; both dug wells and deep wells, 18 points geo-electrical surveys, and chemical analysis of eight groundwater samples. The results showed groundwater flow direction into the Bengawan Solo River with the primary aquifer of the sandstone lens. All groundwater samples indicate that the type of groundwater is calcium magnesium bicarbonate (Ca²⁺ - Mg²⁺ - HCO₃⁻) with one groundwater system. High nitrate content was found in some areas, probably due to contamination from agricultural or urban wastewater. Therefore, it needs some actions for groundwater protection and conservation in this area to support the sustainable use of groundwater.

Keywords: aquifer distribution, geo-electrical survey, groundwater flow, groundwater geochemistry

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Introduction

Water is one of the natural resources needed for human survival. Surface water and groundwater resources support most of the water demand. Groundwater resources are determined by climate, topography, geology, and vegetation (Risha and 2016). Geological Al-Temamy, factors, particularly the type and distribution of rocks, significantly affect the quantity and spatial distribution of groundwater. Many technologies have been developed to determine subsurface conditions, including drilling and geophysical methods. Geophysical methods have advantages compared to other methods, including cheaper and faster processing time (Pazzi et al., 2019). The determination of rock type or geological structure on the geophysical method is based on the physical properties of the material according to the reference values from previous studies (Kirsch, 2006). The geo-electrical survey is one of the geophysical methods suitable for the exploration of the aquifer (Devy and Sarungallo, 2018).

Groundwater flow in an aquifer and its interactions with other aquifers can be identified through groundwater chemical composition studies (Coetsiers and Walraevens, 2006). The chemical concentration of groundwater will increase during the flow process in aquifers (Al-Kalbani et al., 2017). Therefore, groundwater chemical composition not only provides information about groundwater interactions with rocks but also relevant evidence about the geological history of the aquifer layer, rock weathering level, groundwater recharge quality (Fetter, 2001). There are many studies on water type and hydro-chemical facies to provide preliminary information about geochemical processes in groundwater (Thin et al., 2018; Wilopo et al. 2019).

Bojonegoro District is a regency in East Java Province with high population growth, especially in Bojonegoro Sub-district, as the capital of the district. High oil and gas resources is a reason many people come and work in this area. However, the potential for groundwater resources is not yet available. This paper explains comprehensively about groundwater investigations, both aquifer and groundwater quality in Bojonegoro Sub-district, Bojonegoro District, East Java Province, as shown in Figure 1. Research activities were focused on the identification of aquifer layers using the geophysical method and groundwater geochemical.

Materials and Methods

This research is located in Bojonengoro Subdistrict, Bojonegoro District, East Java Province, Indonesia. The groundwater survey was conducted on 31 dug wells and 11 drilled wells. This survey included the coordinates and elevation of wells, depth of groundwater level and measurement of temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) with a pH meter from Besides, Hanna Instruments. groundwater sampling was taken as many as eight samples. Groundwater sampling refers to the Indonesian national standard (BSN, 2008). The ions analyzed from groundwater samples include Ca²⁺, Mg²⁺, Na⁺, K⁺, Cl⁻, HCO₃²⁻, SO₄⁻ and NO₃⁻ with the Ion Chromatography in the Get-In CICERO Laboratory of Geological Engineering Department, UGM, referring to the Indonesian national standard.



Figure. 1. Research area in Bojonegoro Sub-district, Bojonegoro District, East Java Province.

Also, a geo-electrical survey was conducted to identify subsurface conditions so that that lithology can be interpreted as potential layers of aquifer both vertically and horizontally. The geo-electrical survey was carried out as many as 18 points spread evenly in the Bojonegoro Sub-district by using resistivity meter Oyo Mc-Ohm Model 2115A Mark 2. The method of geo-electrical survey used was vertical electrical sounding (VES) with a total length of 500 meters for each measurement (Kirsch, 2006). The geo-electrical method has advantages compared to other geophysical methods because the value of specific resistivity is strongly influenced by the aquifer characteristics (Rubin and Hubbard, 2005). The measurement configuration used the Schlumberger method, which has advantages for the identification of the aquifer layer compared to other methods (Telford et al., 1991). The geo-electrical point, the well location, and groundwater sampling are shown in Figure 2.

Results and Discussion

Bojonegoro Sub-district has an area of 25.71 km² and consisting of 18 villages (BPS-Statistic of Bojonegoro District, 2019). Dander Sub-district borders Bojonegoro Sub-district in the south and west, Trucuk Sub-district in the north and Kapas Sub-district in the east. The rainfall in 2018 was 1900 mm, with 97 rainy days (BPS-Statistic of Bojonegoro District, 2019). While the population in 2018 is 46,068 with a density of 1,792 people/km (BPS-Statistic of Bojonegoro District, 2019). Most of the land use in the study area is dominated by paddy fields with an area of about 1,129.03 ha (44%), followed by settlements of 901.81 ha and moor of 226.75 ha (BPS-Statistic of Bojonegoro District, 2019). The rocks comprise the study area are the alluvial deposits of the Bengawan Solo river consisting of clay, silt, sand, and gravel (Pringgoprawiro and Sukido, 1992).

Morphologically, the Bojonegeoro Subdistrict is located at the point bar of the Bengawan Solo River. The point bar was formed due to the meandering process of the Bengawan Solo River. The meandering process is made by lateral erosion in the outer curve river wall, and the inner curve area occurs deposition because it has weaker flow energy compare to the outer curve. The formed deposition in the inner curve is called a point bar that will be growing as a time function (Charlton, 2008). Relatively large materials will be deposited when the flow energy of a river is high, and finer materials will be deposited by decreasing the flow energy. Therefore, the rock comprising of the point bars has not well consolidated. The process of meandering, development of point bars, and almost a flat river gradients indicate that the river stadia in this area is mature (Strahler, 2013).



Figure 2. Location of wells, groundwater samples, and geo-electrical measurement points in the research area.

Aquifer type and configuration

Geo-electrical measurements were carried out to determine the type and configuration of rock layers in the Bojonegoro Sub-district. The results of the geoelectric survey were combined with surface geological observation data to interpret lithology types. Based on the value of rock resistivity (Todd and Mays, 2005), the lithology that compiles the study area can be grouped into 4, namely:

Soil/surficial deposit

This surficial deposit has a specific resistivity value ranging from 8 to 1,200 ohm-meters. The material that compiles is interpreted as pile material, rock fragments, gravel, and crust. This layer is found on the ground surface.

Claystone unit

The claystone layer is interpreted to have a resistivity value of fewer than 10 ohm-meters. Claystone can store water but cannot drain water or is called an aquiclude. This unit dominates in the research area, where its distribution shows continuity.

Siltstone unit

This siltstone unit is interpreted based on the resistivity value between 10 to 20 ohm-meters.

Siltstone can store and drain water, but the amount is not significant or is called Aquitard. The spread of the siltstone layer is only local and does not affect.

Sandstone unit

The sandstone unit is interpreted from the resistivity value between 20 - 150 ohm-meters. The sandstone unit can store and drain large amounts of water so that it is classified as an aquifer. However, the spread of this layer is only localized so that it forms perched aquifer.

The fence diagram of the geo-electrical survey results is shown in Figure 3. The sandstone layer has a function as an aquifer in lens shape. It is also a similar shape to the siltstone that has a function as an aquitard. The claystone layer (aquiclude) is very dominant and has continuous layers. The repetition of rock layers and the presence of rock lenses indicate that the rocks comprise the Bojonegoro Sub-district are the results of the fluvial deposition of the Bengawan Solo River. There are two types of aquifer, namely unconfined aquifers and confined aquifers in the research area according to geo-electrical data. An unconfined aquifer is dominant in the area close to the Bengawan Solo River, whereas a confined aquifer dominates the farther away from the Bengawan Solo River.



Figure 3. Fence diagram of stratigraphic in the research area based on the geo-electrical survey.

Groundwater flow direction and patterns

The data from field measurement showed the depth of the groundwater level in the study area varied from 0.5 to 11.8 meters. Eight villages that have a groundwater level of fewer than 2.5 meters are Jetak, Klangon, southern Ledok Kulon, southern Ledok Wetan, Pacul, Sumbang, Sukorejo, and Mulyo Agung Sub-districts. Areas with a groundwater level of more than 7.5 meters are parts of Ngrowo, Karang Pacar, Banjarejo, and Ledok Kulon Sub-districts. Groundwater flows direction mostly from south to north, but some local flow to the east, such as in Kalirejo and Semanding Subdistricts, as shown in Figure 4. Groundwater flow to the north and east is caused by the presence of the Bengawan Solo River, which becomes the hydraulic boundary. The direction of the groundwater flow heading north indicates that the southern part of the Bojonegoro sub-district is a recharge area. Therefore, the Bengawan Solo River is a gaining stream that gets water support from groundwater.



Figure 4. Groundwater flow direction in the research area.

Groundwater geochemistry

In general, the pH in the study area is in the range of 6.5 to 7.5. However, in the villages of Ledok Kulon, Ledok Wetan, Kauman, Kepatihan, Kadipaten, and Ngrowo Sub-districts have a pH of less than 6.5. The highest TDS value in the study area was 970 mg/L, and the highest EC value was 1,940 μ S/cm, which was found in Mulyoagung Village. Geochemical data from 8 groundwater samples are shown in Table 1. There is one groundwater sample from Ngrowo Village, which shows a high nitrate content reaching 132.8 mg/L. It indicates that pollution has occurred from urban wastewater and agricultural activities (Xue et al., 2016). Data from chemical test results are plotted on three different diagrams, namely Stiff Diagrams (Stiff, 1951), Schoeller Diagrams (Schoeller, 1965), and Trilinear Piper Diagrams (Hems, 1985). Plotting the results of the chemical composition of groundwater on Trilinier Piper's diagram shows that the type of groundwater in the Bojonegoro Sub-district is only one type, namely calcium magnesium bicarbonate (Ca²⁺ - Mg²⁺ - HCO₃⁻) as

shown in Figure 5. Schoeller diagram of groundwater samples in the Bojonegoro Subdistrict shows that there are only one water facies. It can be seen from the Schoeller diagram pattern, which shows the same pattern for all groundwater samples where the concentration of bicarbonate ions is higher than chloride and magnesium ions are higher than calcium, as shown in Figure 6. Plot stiff diagrams give results in the form of polygons that show specific patterns that have a relatively similar pattern (Figure 7). It indicates that there is only one groundwater system in Bojonegoro Subdistrict. The size of stiff polygons also shows almost the same both in the upstream and downstream areas that indicate no increase in ions concentration. It is probably due to the rock's weathering degree is low, causing only a very few ions are dissolved.



Figure 5. Trilinear piper diagram from groundwater samples in the research area.



Figure 6. Scholler diagram of the groundwater samples in the research area.

No	Location	Temperature (°C)	pН	EC	TDS (mg/L)	Major Ions Concentration (mg/L)							
				(µS/cm)		K ⁺	Na ⁺	Mg ²⁺	Ca ²⁺	SO 4 ²⁻	NO3 ⁻	Cl	HCO ₃ -
1	Sukorejo	28	6.9	950	470	7.11	27.19	21.27	12.68	20.00	0.1	8.10	549.00
2	Ledok Kulon	27	6.6	1040	520	7.71	24.76	20.43	16.96	80.00	12.50	8.09	585.60
3	Kepatihan	29	6.5	1160	580	5.60	39.10	22.78	15.23	45.00	31.40	8.09	671.00
4	Ngrowo	28	6.8	800	400	3.05	38.61	27.37	6.67	20.00	132.80	8.08	366.00
5	Semanding	30	6.7	1830	920	51.33	57.15	46.36	10.47	100.00	23.30	8.08	671.00
6	Campurejo	32	7.3	1160	580	7.24	39.10	22.78	9.03	60.00	0.1	8.07	463.60
7	Kalirejo	29	7.0	1270	630	4.28	24.05	30.4	16.87	100.00	23.90	8.07	463.60
8	Pacul	30	7.3	1350	670	2.24	44.99	24.33	9.52	109.74	0.1	8.08	488.00

Table 1. Groundwater chemical composition.

Note: EC = Electrical Conductivity; TDS = Total Dissolved Solid.



Figure 7. Stiff diagram of the groundwater sample in the research area.

Conclusion

Bojonegoro Sub-district is composed of sandstone, siltstone, and claystone from fluvial deposits of the Bengawan Solo River. The layer that has a function as an aquifer is sandstone, but the distribution of this layer is not continuous. Therefore, the potential of groundwater resources in the Bojonegoro Sub-district is not large enough. Bojonegoro Sub-district has only one groundwater facies is Calcium Magnesium Bicarbonate (Ca²⁺-Mg²⁺-HCO₃⁻). Also, there is only one groundwater system in this area, wherefrom upstream to downstream shows the same pattern, and no significant increase in ion concentration. If pollution occurs in the upstream area, it will spread to all areas in the downstream. High nitrate concentration in Ngrowo Village indicated groundwater contamination due to urban wastewater and agricultural activities. The exploration of alternative water resources needs to be conducted because of the limitations of groundwater resources and the increasing water needs. It is necessary to look for alternative sources

of water from surface water, such as the Bengawan Solo River. Besides, it is recommended to develop retention ponds to increase groundwater recharge, especially in the area of sandstone.

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