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Groundwater quality of unconfined aquifer in Demak Regency, Indonesia

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Abstract. Industry and society utilize groundwater to meet their daily needs. The study area is located in Demak Regency, which is located in the northern part of Java Island. Administratively, Demak Regency covers 14 districts with a total population of up to 1.16 million inhabitants. The utilization of unconfined groundwater is an alternative to meet the needs of the community. The condition of the unconfined aquifer, which is the source of fresh water for the community, must meet the standards for public health. Thus, it needs a fundamental assessment of the condition of the unconfined aquifer in Demak Regency. The evaluation of unconfined aquifer is focused on physical and hydrogeochemical analysis. The method used was a field campaign by measuring the groundwater depth and analyzing 30 groundwater samples for physical and chemical analysis. The results of measurements of pH values in groundwater samples in the study area are between 6.68-7.84. The high pH is in the Districts of Mranggen and Kebonagung. Furthermore, the value of electrical conductivity (EC) is between 678-3,130 µS/cm. The samples that are close to the Java Sea conduct a higher EC value, which is located in the Sayung, Karangengah, Bonang, and Wedung Districts.

1. Introduction

Water is one of the primary needs of society. One source of fresh water comes from dug wells. As a source of freshwater, hydrogeological factors and water quality are essential. Groundwater hydrogeological conditions are groundwater depth and its level from sea level. Water quality analysis is used to determine the composition of water for groundwater management [1]. Groundwater quality depends on various factors, such as geological conditions, lithology, aquifer properties, soil types, and others [2]. Changes in groundwater quality can be influenced by interactions between water and rocks or the influence of human activities [3]. Human activities such as industrial activities, household activities that produce domestic waste, and agricultural activities can affect groundwater quality [4]. Domestic wastes such as uncontrolled use of detergents and pesticides have a negative impact on groundwater quality. Excessive groundwater extraction around coastal areas can destroy the balance between fresh and saltwater in coastal aquifers [2, 5].

Groundwater quality assessment can be determined from pH and electrical conductivity (EC) [6] values. The pH value is the number of H^+ and OH^- elements, both from contaminants and from solutes.

The more elements H^+ effect the lower the pH value, and the water is acidic. If the water contains a lot of OH^-, the pH value is higher, and the water is alkaline. Conductivity (EC) is the ability of water to conduct electricity. The dissolved salt content in water will affect the conductivity value. The more salt dissolved, the higher the electrical conductivity value [7].

Demak Regency is located directly adjacent to the capital city of Central Java Province, namely Semarang City. Intensive groundwater used has an impact on the development of Demak Regency, which is also increasing in the population. The location of Demak Regency, which is on the coast, makes economic activity increase rapidly [8-9]. The population in Demak Regency is 265 million people with a population growth rate of 1.19% [10]. Population growth and urbanization in the coastal area put pressure on natural resources that cause damage, including the quality and its groundwater quantity [9]. While the rice field and settlement areas are the primary land use in the study area, as shown in figure 1.

The purpose of this study is to determine the hydrogeological condition and quality of groundwater through interpolation of quality data and its visualization on graphic interpretation. Groundwater quality assessments such as pH and EC are used for groundwater management.

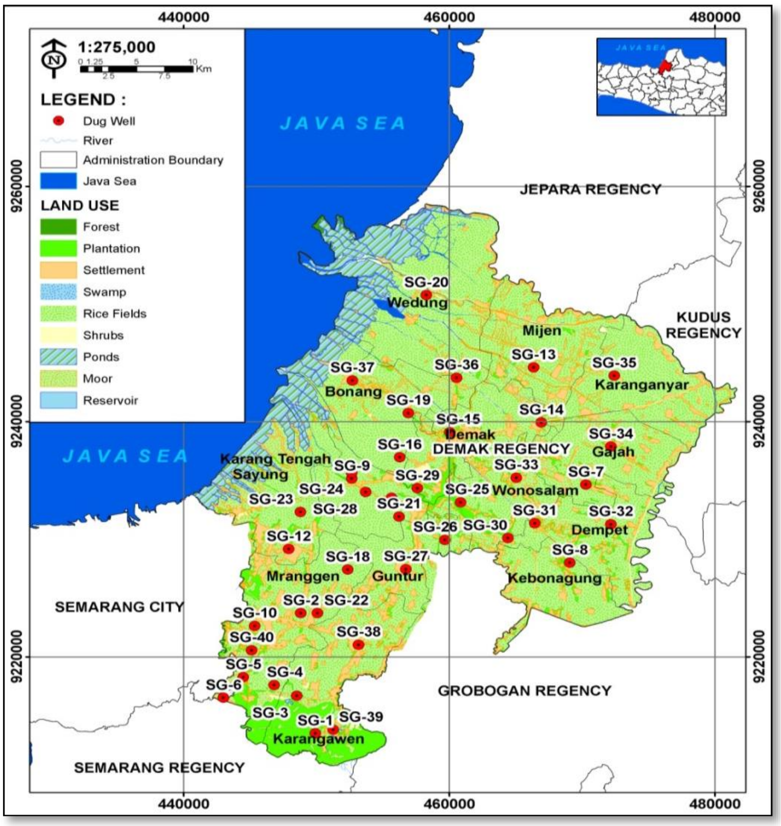

Figure 1. Land use in the study area

2. Geologic and hydrogeologic regional setting

2.1. Geology

The morphology of the research location consists of plains and hills with an elevation between 0-234 masl (meters above sea level). The types of lithology that are arranged in the morphology of the plains are alluvium (Qa) and the Damar Formation (QTd). The coastal plain is generally composed of clay and sand that reaches a thickness of up to 50 meters or more. Sand deposits typically form deltaic deposits as water-carrying layers with a thickness of up to 80 meters more. River and lake sediment consists of gravel, gravel, sand, and silt. The rocks are mainly andesite, limestone, and sandstones. They are Holocene.

The Damar Formation consists of tuff, conglomerates, volcanic breccia, sandstones containing mafic minerals, feldspar, and quartz. The volcanic breccias were probably deposited as lava. This formation is partly non-marine. Local mollusks are found and remain of vertebrates. This unit is thought to be in the Early Pleistocene [11]. The morphology in the south is hilly areas with a distribution of only 5% of the total area. Types of lithology that are composed of hilly morphology are the Kalibeng Formation and the Kerek Formation. The Kalibeng Formation consists of marl, tuffaceous sandstone, and limestone. Whereas the Kerek Formation consists of interlacing claystone, marl, tuffaceous sandstones, conglomerates, volcanic breccias, and limestone [11].

2.2. Hydrogeology
According to [12], the aquifer of Demak Regency is divided into 2 types. Aquifers in which flow is intergranular, which are divided into small aquifer productivity, medium aquifer productivity, and productivity of local aquifers. The rest is aquifers in which flow is fissured or porous of low productivity and region without groundwater exploitation. According to [13] natural flow conditions in the study area are divided into two, namely, groundwater flows in alluvial plains and hilly areas.

Groundwater in alluvial plains flows through a porous medium from high-pressure areas to low-pressure areas. Regionally groundwater in the alluvial plain flows from the south-southwest to the north-northeast. The groundwater level tends to decrease to the north. Groundwater flow in the hilly area located in the southern part of the Demak Regency area flows from the south in the west-central part and to the northeast in the eastern region.

3. Methods
The study area is in Demak Regency with a total area of 897.43 km^2. The data collection method was accomplished by using hydrogeological mapping. It was carried out by measuring the depth of the groundwater level and the elevation of the dug wells. Furthermore, it was also conducting groundwater samples to analyze the pH and EC values. There were 40 measurement points of the dug wells as well as conducting groundwater samples (Figure 2). Geographic information systems (GIS) were applied to analyze the hydrogeological mapping data. According to [14-15], GIS is a useful tool for identifying mapping on the regional scale and in the groundwater problems such as groundwater pollution. Spatial analysis in GIS was applied to interpolate the hydrogeological mapping data. The results of groundwater level measurements, pH, and, EC were interpolated by using spatial analysis. It described the groundwater level conditions and groundwater quality in all research areas [16]. Furthermore, groundwater quality maps can be used to assist the planning, management, and evaluation of potential contamination from various sources of groundwater management and groundwater pollution [14-15, 17].

4. Results and discussion

4.1. Hydrogeological condition
Hydrogeological conditions include groundwater level depth, groundwater level, and its direction. The results of the hydrogeological mapping show that the depth of the groundwater level is 0.1-4.4 m, as shown in Table 1. Furthermore, the groundwater level is between 1.9-144.9 masl. The results of the spatial analysis, it shows that the south side of the study area has a deeper groundwater level (Figure 3). The southern part of the research area includes Karangtengah, Sayung, Guntur, Mrangen, Karangawen, and Kebonagung sub-districts have a groundwater level between 0.5-3 m. In comparison, the northern part of the research area includes Sayung, Bonang, Wentuk, Mijen, Karanganyar, Demak, Gajah, Dempet and Wonosalam sub-districts have a groundwater level of 0.1-0.5 m.

The results of the spatial analysis of groundwater levels also show that the southern part of the study area has a higher groundwater level than the south (Figure 4). The south of the research area includes

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Guntur, Mranggen, Karangawen, Kebonagung, and Dempet Districts which have groundwater levels between 10-45 masl. Meanwhile, the northern part of the research area has a groundwater level between 0-10 masl.

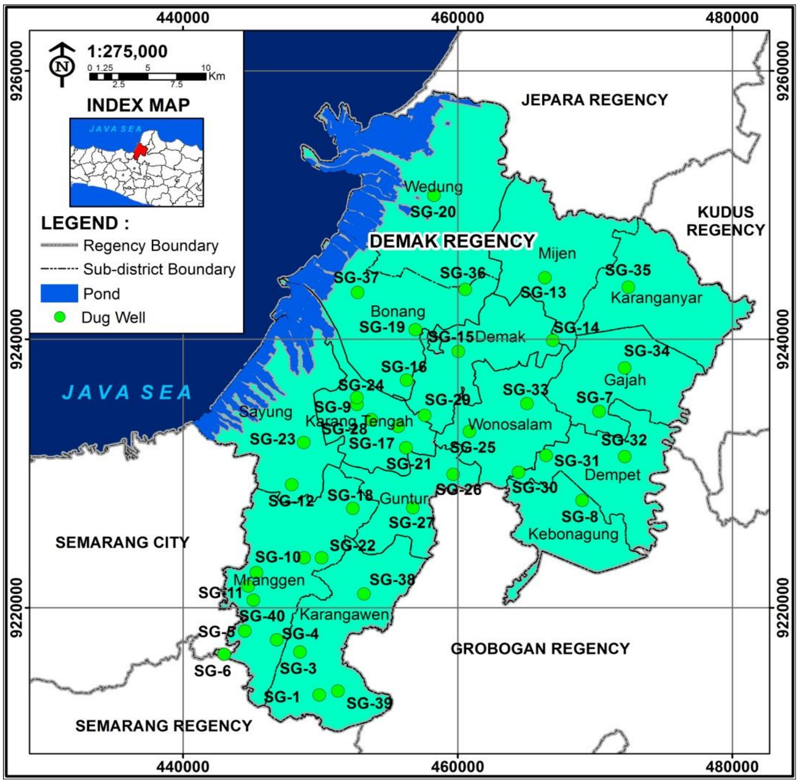

Figure 2. Location of interest points in the hydrogeological mapping

Table 1. Descriptive statistic hydrogeological mapping of the dug wells

Variable	Min	Max	Ave	SD
Groundwater depth (m)	0.1	4.4	0.99	1.01
Groundater level (masl)	1.9	144.9	19.18	30.58

From the results of the analysis of the depth and its level, it can be concluded that the groundwater flows from the south to the north of the study area. It follows the topographical which is lower to the north.

4.2. Groundwater quality

Groundwater quality which is measured, includes pH and EC parameters. pH is a fundamental property that describes the acidity and alkalinity of groundwater [15]. The results of measurements of 40 groundwater samples show that the pH value was between 6.68-7.84, as shown in Table 2. According to [18-19], from 40 samples of pH test follow all met the minimum and maximum allowed limits (Figure 5). A pH value that exceeds the specified limit has no direct impact on health in the short term. However, the use of water with a pH value that exceeds the specified limit should be limited and avoided for consumption.

Figure 3. Map of groundwater depth

Figure 4. Map of the groundwater level and its direction

Table 2. Summary of groundwater quality

Variable	Min	Max	Ave	SD
pH	6,68	7,84	7,15	0,24
EC (µS/cm)	678	3.130	1350,2	557,91

The EC value indicates 678-3.130 µS/cm (Table 2). EC can be classified into type 3 types according to [15, 20]. Type I if the salt enrichment is low (EC <1,500 µS/cm). Type II if the salt enrichment is moderate (EC 1,500-3,000 µS/cm). While type III if the salt enrichment is high (EC> 3,000 µS/cm). Based on the classification, there are 65% of the samples belonging to type I, 32.5% of the samples are type II, and 2.5% of the samples are type III.

The results of the spatial analysis show the distribution of the EC value in the research area where the EC value is getting higher towards the north (Figure 6). It means that the closer to the coastline, the EC value is high. It indicates that the groundwater is influenced of seawater. However, it was found that the location of the highest EC measurement is far from the coastline of the Java Sea. The maximum EC value (3,130 µS/cm) is in Bantengmati Village, Mijen District, and is about 15 km to the south of the Java Sea coastline. The location which is relatively far from the coastline, indicates the presence of ancient water (connate water). Connate water is water trapped in sediment and has a high salt content. It can be concluded that the factors that influence the EC value are apart from the distance from the coastline indicate the presence of ancient water.

5. Conclusion

The hydrogeological condition in the northern part of Demak Regency has a shallower groundwater depth compared to the southern part. The groundwater level on the north is lower than the south. The direction of groundwater flow follows the topography from south to north towards the Java Sea. Based on the pH value of groundwater quality in Demak Regency, it is between 6.68-7.84. The EC value in Demak Regency ranges from 678 to 3.130 µS /cm. The closer to the shoreline, the higher the EC value. It indicates the seawater affects groundwater. There are groundwater samples that show high EC values, even though they are far from the coastline. Thus, it describes the existence of ancient water (connate water).

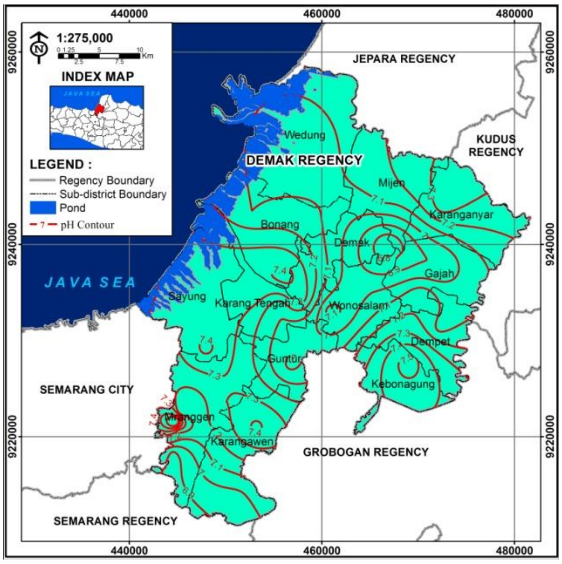

Figure 5. Map of pH

Figure 6. Map of Electrical Conductivity

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