The assessment of Groundwater Quality of Confined Aquifer Based on Hydrochemistry in the Alluvial Plain of Semarang City

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Abstract. Water is one of the most important components for living things, including humans. The need for water will increase along with the increase in population in an area. It occurs in urban areas such as Semarang City which is the capital city of Central Java Province with the development of industry, trade and tourism growing rapidly. Rapid development occurred in the alluvial plains of Semarang City. Groundwater is still one of the main sources of water in Semarang City, both unconfined aquifer and confined aquifer. The unconfined aquifer is generally used by the community to meet their needs for bathing and washing via dug wells, while the confined one is developed by the industrial sector and is not least a source of drinking water via deep wells. This study aims to determine the quality of groundwater for drinking water at the study site of the confined aquifer. There are 30 groundwater samples were taken to test the chemical content of groundwater. The method used was the geospatial method and the Water Quality Index (WQI). The spatial method aims to determine the distribution of groundwater quality in the study area. WQI method was to determine the quality of groundwater for drinking water purposes. The results of the hydrochemical analysis showed that groundwater conditions are affected by weathering of silicate minerals present in the lithology of the study site. The weathering of these minerals results in ionic changes in the groundwater. WQI shows 1 sample is included in the poor classification and 2 samples are included in the very poor classification. It locates in the western and central parts of the study location.

1 Introduction

Water is an important factor that supports life. The earth's surface is covered by water by 70%. Of all types of water, fresh water on earth is only 2.53% [1][2]. Sources of fresh water on earth can be obtained from surface water such as river water, lake water and swamp water. Besides that, other sources of fresh water come from underground water or groundwater. Groundwater is water that is below the soil surface below the saturation zone [3]. According to Law (UU) No. 17 of 2019 concerning Water Resources [4], it explains that groundwater is water that can be found in the layers of soil or rock below the surface of the soil. Currently,

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the source of water that is widely used by Indonesian people comes from groundwater [5]. This is because the quality of groundwater is considered relatively better and does not require water treatment. The community also considers that groundwater is easier to obtain and is much cheaper in terms of costs compared to using other water sources.

Groundwater potential in Indonesia reaches 520 billion m^3/year where Java Island ranks 4th with the largest distribution of groundwater potential [6]. Considering that Java Island is the region with the highest population density in Indonesia, it is not comparable to the available groundwater potential. Semarang City is one of the provincial capitals with a significant population density. It is recorded that the population has increased from 1.65 million people in 2020 to 1.66 million people in 2021 [7]. This increase was caused by rapid industrial and commercial development [8], resulting in urbanization and migration of people also increasing. Growth in population density is often inversely proportional to the availability of clean water. Higher population growth results in increased water use which reduces the availability of clean water [9].

Morphologically, the city of Semarang is divided into two, namely hilly areas and plains areas. It is known that the city of Semarang is directly adjacent to the sea in the north and has a coastline length of 13.6 km [7]. The morphological conditions of the City of Semarang make a difference in the development of the city, where the development of the plains area is more advanced than the hilly area. This is because the plains area is considered to have more conducive environmental conditions for settlements and industrial areas. As a result, groundwater exploitation tends to increase and is usually not replenished [10]. Excessive exploitation of groundwater results in a decrease in the amount and quality of groundwater [11]. Seeing the current environmental conditions and large use of groundwater in Semarang City, this research is focused on the Alluvial Plains area of Semarang City (Figure 1).

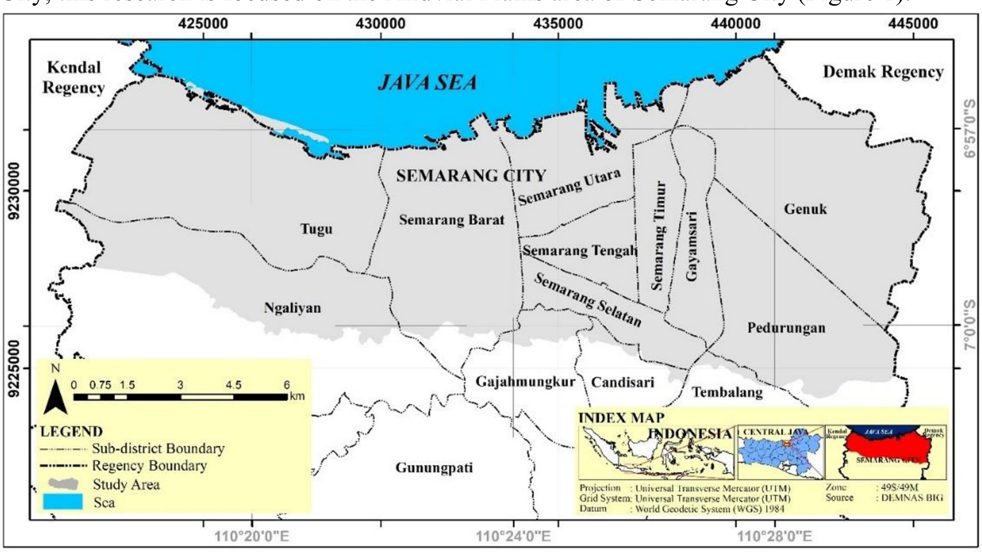

Fig. 1. The study area is in the alluvial plains of Semarang City.

The large use of groundwater in Semarang City and the lack of efforts to restore groundwater have resulted in increasingly limited groundwater availability. The limitations of groundwater include the limited amount that can be extracted and the limited quality of groundwater that can be utilized. Given the large use of groundwater for domestic and industrial purposes, analysis of groundwater quality is a fundamental activity to determine the condition of groundwater that can be used to support human life. Groundwater is experiencing quality degradation caused by rapid urban development, industrialization and unwise use of water for agricultural water, both groundwater and surface water [12]. Groundwater quality is influenced by various factors, such as geological conditions, lithology, aquifer properties, soil types and others [13]. According to [14], changes in groundwater quality can be influenced by interactions between water and rocks or by the influence of human activities. Human activities such as industrial activities, household activities that produce domestic waste and agricultural activities that produce agricultural waste [15]. Groundwater quality assessment can be carried out by conducting groundwater hydrochemical investigations [16]. Groundwater hydrochemistry is not only influenced by natural factors such as geological, geographic and climatic conditions but is also influenced by anthropogenic factors [17-20].

Several groundwater quality assessment methods can be used to determine groundwater quality. A popular method used in various parts of the world is the assessment of groundwater quality using the WQI (Water Quality Index) method. This method plays an important role in the assessment of overall groundwater quality because it gives effect groundwater chemical parameters on overall water quality [21]. WQI is an assessment of the quality of groundwater for drinking water with a weighting method. Physico-chemical parameters are weighted according to their level of importance or not for human health problems [22]. In giving the weight there are no specific provisions or exact values, but based on the conditions of the research location and the groundwater environment.

The WQI method has been used by several researchers with various regional characteristics. WQI has been used to assess groundwater quality for volcanic areas [23], lowland areas with loose aquifers [24][25] and even oasis areas [26]. Sener [27] evaluated water quality using the WQI method in SouthWest Turkey and reported a range of WQI values between 36-338 indicating good quality for drinking water purposes.

The results of hydrochemical analysis using WQI are represented on a digital map using the Geographic Information System/GIS method. The GIS provides digital information and analysis of the earth's geographic surface [28]. The GIS method is used to determine the distribution of groundwater quality based on the physicochemical parameters of groundwater. A study on hydrochemical characteristics and evaluation of groundwater quality has been carried out in Tamil Nadu, India using GIS and the researchers stated that the GIS is an effective tool to identify polluted and non-polluted zones [29]. [30], conducted a groundwater quality assessment using the GIS method in the Modjo River Basin, Central Ethiopia. The method used is IDW interpolation to determine the distribution of groundwater quality at the study site. The interpolation results show the interpolated spatial variations of the pH, EC, TDS and major ion values. The GIS is used to accumulate, analyze and display spatial data for decision-making in several fields including the field of environmental geology [31].

Considering the wide use of groundwater for humans, groundwater quality assessment becomes very important. The purpose of this study was to assess the suitability of groundwater quality for drinking water in the alluvial plains of Semarang City. Assessment of groundwater quality for drinking water uses the WQI method. The results will be represented using the GIS.

2 Materials and Methods

2.1 The study area and data collection

The study area is located in the northern part of Semarang City (Figure 1) which is geographically located between 420864 - 445519 m (East)/$6^0$55' 52.3” - $7^0$1' 5.3” and 9224184 - 9233797 m (North)/ $110^0$17' 0.6” - $110^0$30' 24.5”. The elevation of the research location is between 0-133 masl. In terms of geological conditions, the research location consists of Damar Formation and alluvium. The Damar Formation is a volcanic deposit composed of tuffaceous sandstones, conglomerates and volcanic breccias. Meanwhile, alluvium is a sedimentary deposit composed of gravel, gravel, sand, silt, and clay (Figure 2) [32]. Availability of groundwater at the study site is divided into 3 groups, namely high availability of groundwater with a discharge of >5L/s, medium availability of groundwater with a debit of between 2-5 L/s, and potential for brackish to salty water (Figure 2) [33]. The data collection method was carried out by taking groundwater samples from 30 points spread throughout the study locations. The physico-chemical parameters of groundwater used in this study include: TDS, EC, pH, Hardness, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, K^{+}, Na^{+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_2^-, and NO_3^-.

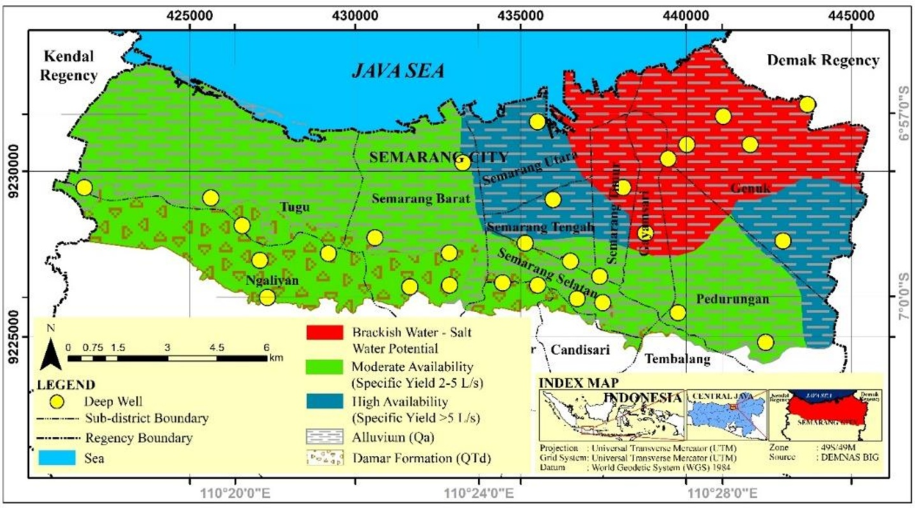

Fig. 2. The study area is in the alluvial plains of Semarang City. The regional geological setting from old to young is composed of the Damar Formation and Alluvium. The availability of groundwater is divided into 3, namely high to medium groundwater availability and brackish/saltwater potential.

2.2 Water Quality Index (WQI)

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In this study, groundwater evaluation for drinking water consumption was carried out using the groundwater quality weighting method based on the Water Quality Index (WQI). Each parameter is weighted according to its effect on health. The relative weight value (Wi) is obtained from Equation 1.

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad (1)$$

Where Wi is the relative weight, Wi is the weight given to each parameter (Table 1), and n is the number of parameters. Next was to calculate the quality rating scale (qi) for each parameter. The qi value was obtained from the comparison of the parameter value (Ci) to the set standard value (Si) multiplied by 100, so the qi value is obtained from Equation 2.

$$qi = \frac{Ci}{Si} \times 100 \quad (2)$$

To calculate the WQI value, first look for the subindex (SI) value of each parameter used using Equation 3.

$$SI = Wi \times qi \quad (3)$$

To calculate the WQI value, Equation 4 was applied.

$$WQI = \sum SI \quad (4)$$

Classification of groundwater quality for drinking water using WQI was divided into 5 classes (Table 1).

Table 1. Classification of groundwater quality for drinking water based on WQI values [11]

WQI range	Water Quality
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
>300	Unsuitable

2.3 Spatial distribution map

Sampling locations marked using the Global Positioning System (GPS Garmin 64s) were imported into the GIS (Geographic Information System) for further interpolation using the Kriging method. Interpolation was developed in digital terrain modelling to determine the value of a point based on known point values. Interpolation was the process of predicting the value of a point that is not a sample point, based on values from surrounding points that are sampled [34]. [35] explained that interpolation was a formula for finding the height of a point flanked by two other points with the concept of a similar triangle. The Kriging interpolation method was based on the concept of geostatistics which utilizes spatial values at sampled locations and variograms to predict values at other locations that have not been or were not sampled where the predicted value depends on their proximity to the sampled locations [36].

3 Results and Discussion

The results of the research analysis were based on 15 physicochemical parameters from 30 groundwater samples scattered in the study locations. Based on the 2017 WHO quality standards [37], all groundwater samples show that the quality of groundwater exceeds the permissible standards. As a result, the use of groundwater as a source of clean water is disrupted and can cause health problems for humans. Table 2 shows the parameters used in this study. Weight values, minimum, maximum, and average, for each parameter are presented in Table 2.

In this study, the assessment of groundwater quality for drinking water uses the WQI method. The parameters used were 15, namely Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, K^{+}, Na^{+}, pH, SO_4^{2-}, HCO_3^{-}, EC, TDS, Cl^{-}, NO_3^{-} and NO_2^{-}. Furthermore, the rules for limiting the permissibility of an element contained in water are based on WHO 2017 [37] (Table 3). The groundwater quality distribution map for drinking water using the WQI method was compiled using a GIS and presented in Figure 5. To calculate the WQI value at each sampling point, assign a weight value to each parameter based on the relative importance of drinking water needs. The weighting for calculating groundwater quality using the WQI method is 2 to 5. The weight of 2 is given to the parameters Hardness [38] Ca^{2+}, Mg^{2+} [27], Fe^{2+}, Mn^{2+} [12], K^{+} and Na^{+} [31]. A weight of 3 is given to the pH parameters, SO_4^{2-} [31] and HCO_3^{-} [27]. A weight of 4 is given to the parameter EC [30]. While the highest weight with a scale of 5 is given to the parameters TDS [31], Cl^{-} [12], NO_3^{-} and NO_2^{-} [27]. The results of calculating the WQI value were around 33.5 -

269. Based on the classification of groundwater quality, the groundwater samples at the study site were divided into 4 groups (Table 3), namely: excellent, good, poor quality, and very poor quality for drinking water. The percentage of each water quality is presented in the form of a pie chart in Figure 4.

Table 2. Chemical and Physical Parameter

Parameter	Unit	WHO [37]	wi	Wi	Min	Max	Ave	SD
TDS	mg/L	1,000	5	0.11	254	4,241	789	861
EC	µS/cm	1,000	4	0.10	380	6,330	1,177	1,285
pH	-	6.5-8.5	3	0.06	6.4	864	7.24	0.6
Hardness	mg/L	500	2	0.04	18	1,368	236	239
Ca^{2+}	mg/L	75	2	0.04	0	390	46.4	69
Mg^{2+}	mg/L	50	2	0.04	0.9	76.9	19.1	17.2
Fe^{2+}	mg/L	0.3	2	0.04	0	2.3	0.1	0.4
Mn^{2+}	mg/L	0.4	2	0.04	0	1.2	0.2	0.3
K^+	mg/L	12	2	0.04	5.8	82.4	17.8	16.5
Na^+	mg/L	200	2	0.04	14.3	996	169	186
HCO_3^-	mg/L	120	3	0.06	140	525	293	102
Cl^-	mg/L	250	5	0.11	236	1,623	199	398
SO_4^{2-}	mg/L	250	3	0.06	0	230	54.4	49.7
NO_2^-	mg/L	3	5	0.11	0	0.05	0	0.01
NO_3^-	mg/L	50	5	0.11	0	62.5	9	15.1
			Σ=47	Σ=1.00				

Table 3. Classification of groundwater quality based on WQI

Value Range	Quality	Total No. Samples	Percentage (%)
33.5-50	Excellent	8	27
51-100	Good	19	63
101-200	Poor	1	3
201-269	Very Poor	2	7

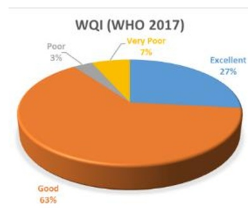

Fig. 4. WQI Diagram

Groundwater samples from locations SB11, SB12, SB14, SB19, SB25, SB30, SB35, and SB41 are classified as groundwater with excellent. Groundwater samples from locations SB1, SB4, SB6, SB9, SB13, SB16, SB17, SB18, SB20, SB26, SB29, SB33, SB37, SB38, SB39, SB42, SB43, SB44, and SB45 are classified as groundwater with good quality. Groundwater samples from location SB23 are classified as groundwater with poor quality. Groundwater samples at locations SB7 and SB10 are classified as groundwater with very poor quality. The distribution map of WQI values (Figure 5) shows that the quality of groundwater in the western and central parts of the study location is very poor. The western part of the research location is represented by location SB10 where groundwater quality is influenced by the parameters TDS, EC, Mg^{2+}, K^+, Na^+, HCO_3^- and Cl^-. The middle part of the research location is represented by SB7 and SB23 where the groundwater quality is influenced by the parameters TDS, EC, Hardness, Ca^{2+}, Fe^{2+}, Mn^{2+}, K^+ and Cl^-.

4 Conclusion

Groundwater quality is an important aspect in groundwater utilization. The quality of groundwater can be assessed from the hydrochemical conditions of the groundwater. It will describe how the groundwater is formed and what factors affect the quality of the groundwater. The assessment of groundwater quality for drinking water is based on the hydrochemical conditions of 30 groundwater samples spread over the study area. The method used to assess the quality of groundwater for drinking water is the Water Quality Index (WQI). This method is a weighting method based on the provisions of the maximum limit of each substance allowed by the World Health Organization [37].

The results of the analysis of groundwater quality for drinking water using the WQI method found that from 30 samples of groundwater, it is categorized into 4 classifications, namely; 8 samples are excellent, 19 samples are included in the good classification, 1 sample is included in the poor classification, and 2 samples are included in the very poor classification.

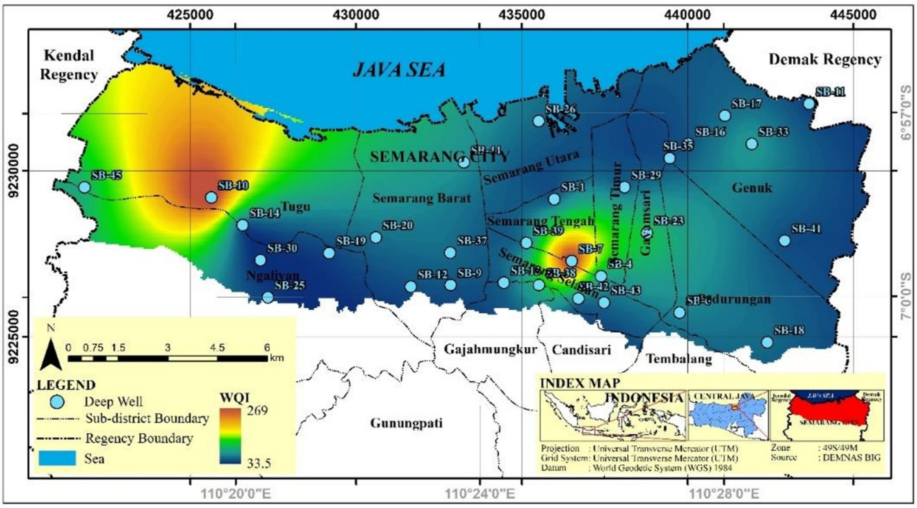

Fig. 5. Groundwater quality distribution map for drinking water based on the WQI method

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