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Assessment of Groundwater Quality to Achieve Sustainable Development in Semarang Coastal Areas

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Abstract. Semarang is growing fast particularly in the industrial and commercial sectors. Hydrogeological mapping and spatial analysis were used to assess groundwater quality in Semarang coastal areas. Results conduct that water table varies from 0.03 to 17.5 m depth and flows from the south to the north which is following topography i.e. higher to the south. pH values range from 6.05 to 8.17 while DO is up to 1.5 mg/L. EC values reach up to 6,370 μ S/cm in the north as well as the maximum salinity value is around 3,600 mg/L related to the excessive groundwater used and sea water intrusion.

1. Introduction

Water quality analysis is one of the most fundamental aspects of groundwater studies. Knowledge of processes that control natural water composition is needed for groundwater management [15]. Assessment of groundwater quality is possible to understand the change in quality due to rock-water interaction or impacts of anthropogenic influence [11]. Groundwater often consists of major ion elements i.e. Ca^{+2} , Mg^{+2} , Na^{+1} , K^{+1} , Cl^{-1} , HCO_3^{-1} , and SO_4^{-2} . These ions can be plotted into some graphs such as Stiff and Piper diagrams. The Stiff system shows the differences or similarities in water and changes in water composition. While Piper diagram depicts the groundwater facies to understand as well as to identify the hydrochemistry composition in different classes. Indeed, pH, electrical conductivity/eC and Dissolved Oxygen/DO values can be employed to assess groundwater quality. The pH of water represents the relative amount of free hydrogen (H^+) and hydroxyl ions (OH^-). It is most affected by soils through which the water flows. Additionally, many factors influence the pH of water such as the source of water, precipitation, and input of contaminants. The fundamental use of pH in water analysis is an indicator of relative acidity or alkalinity of water. Values of 9.5 and above indicate high alkalinity whereas values of 3 and below indicates acidity. The normal pH range for drinking water is from 6.5 to 8.5. Meanwhile, the eC value of water estimates the total amount of solids dissolved in water. It is a valuable indicator of the total salinity, especially in the coastal area. Moreover, DO analysis measures the amount of Oxygen (O_2) dissolved in an aqueous solution. Adequate dissolved O_2 is fundamental for good water quality. It is an essential element to all form of life. An extremely high or low of the DO level can harm aquatic life and affects water quality. Thus, DO value can be applied to investigate the changing of water quality e.g. seawater intrusion in the coastal area. Saltwater contains less O_2 than freshwater [3].

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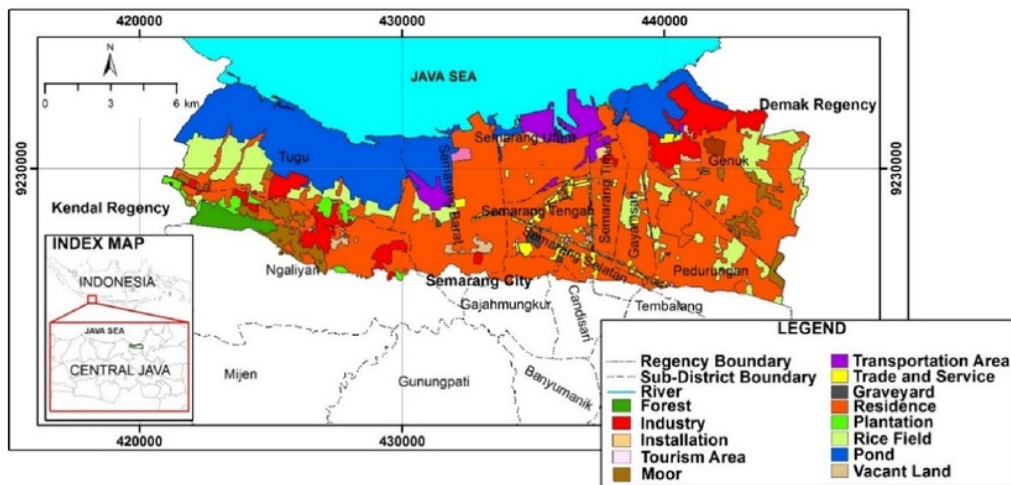


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2 Semarang, as one of the urban coastal cities in the central north of Java Island, is growing fast, in particular in the industrial and commercial sectors [10]. Semarang has two morphological features. Coastal plains and lowlands are located in the north while in the south is represented by highlands. The land use of coastal plains and lowlands is dominated by residence, ponds, and trade and service areas (Figure. 1). Meanwhile, the highland region is mainly for plantation, park, and residence in some part. The study area of this research is focused on coastal plains and lowlands of Semarang due to some environmental problems such as lowering the water table, subsidence, flooding, seawater intrusion, and degradation of groundwater quality occur in that areas as the latest happened in early 2014 [7]. The increasing population (0.65% per year, [13]) in the urban coastal city such as Semarang affects an enormous stress on the natural resources – groundwater, in particularly. Groundwater represents the most valuable drinking water resource. The purpose of this research is to assess of groundwater quality via some graphical interpretation as well as interpolation of water quality data on maps. The assessment will provide the actual condition of groundwater quality data such as the major concentration of cations and anions, pH, eC, and DO values to achieve sustainable development of groundwater management in Semarang coastal plains and lowlands.



20 **Figure 1.** Study area and its land use. Coastal plains and lowlands of Semarang are located in the central north of Java Island (Indonesia) and a capital city of Central Java Province (Index map). They are dominated by residence in the north, in the city centre to the east while the rest is mainly occupied by ponds, trade and service areas.

2. Geologic and hydrogeologic setting

Coastal plains and lowlands of Semarang is located in the northern to the centre area of Semarang. Topography is around 0 to 15 meters above sea level (masl). Semarang has two seasons i.e. the dry and rainy seasons. The average of air temperature and rainfall from 2010 to 2014 is 28°C and 2,396 mm/yr respectively [13]. The peak of the rainy season usually occurs from December to January whereas August to September mostly the lowest precipitation takes place.

Regionally, stratigraphy of coastal plains and lowlands of Semarang from young to old consists of surficial deposits and sedimentary rocks (Figure. 2). Based on the regional geological map of Semarang [6], sedimentary rocks consist of Damar Formation which is composed of tuffaceous sandstone, conglomerate, and volcanic breccia. The latter occurs as lahar deposit in the centre to the south of lowlands. Surficial deposits as the youngest spread from lowlands in the centre to coastal plains in the north of Semarang. The coastal plains is composed by basin sediments [5]. The bulk of the basin

sediments is dominated by alluvium. It is dominated by thick layers of calcareous and shell bearing clay with thin intercalations of sand and occasionally gravel to pebble or cemented gravel.

Some researchers describe that there are two aquifer systems in Semarang: i.e. confined and unconfined aquifers [12, 1, 10]. The aquifer which is separated by confined unit (thick of clay layer) is confined aquifer. The aquifer is composed of sedimentary marine and volcanic rocks in the lowlands and highlands of Semarang respectively. Groundwater in this aquifer is mainly abstracted for industrial purposes. Meanwhile, the unconfined aquifer consists of alluvial deposits. The unconfined aquifer (as the main focus of this research), groundwater flows from lowlands in the south to coastal plains in the north predominantly in an intergranular system. Fluctuation of water table appears depending on the season: high and low in the rainy and dry seasons, respectively. Groundwater is exploited by numerous dug wells, mainly for domestic water supply.

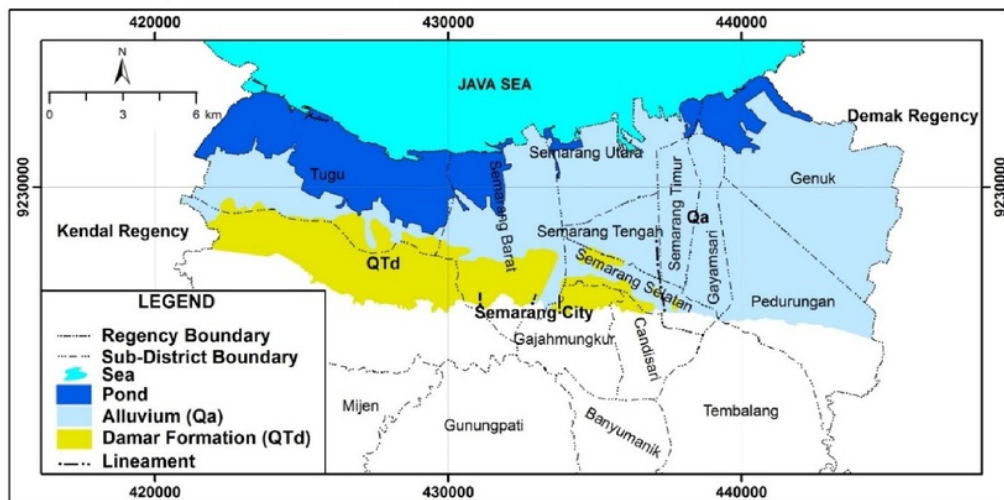


Figure 2. Geological map of Coastal plains and lowlands of Semarang (adapted from Thanden et al., 1996). Alluvium (Qa) spread in almost whole coastal plains and lowlands of Semarang while in the south of Semarang consists of Damar Formation (QTd).

3. Methods

To provide groundwater quality data, hydrogeological mapping was conducted in May 2016. Measuring water table and hydrochemistry properties such as pH, eC, salinity, and DO values were collected from one-hundred fifty (150) dug wells by using the water level meters and the WTW Handheld of pH (3210) meters, Conductivity (3110) meters, and Oxygen (3310) meters (Figure. 3). These hydrochemistry data were then interpolated by using spatial analysis and depicted into the hydrochemistry maps to analyse the actual hydrochemistry condition of the unconfined aquifer in coastal plains and lowlands of Semarang. Furthermore, to define the groundwater facies and its composition, six selected samples were analysed of major cations and anions in the Laboratory of Health at the Central Java Province. The results were plotted onto some graphs i.e. Piper and Stiff diagrams in the maps. The groundwater conservation zone was developed according to the hydrochemistry data.

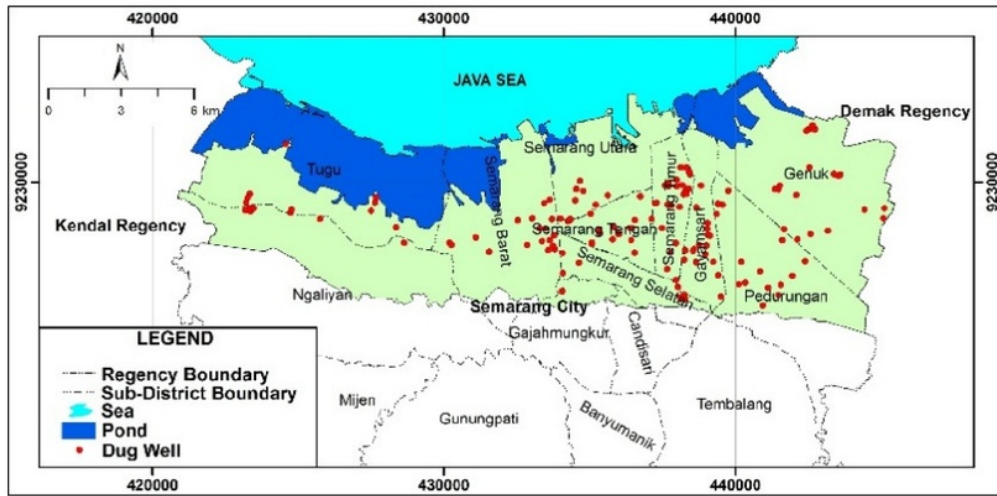


Figure 3. Location of groundwater samples from dug wells. The rapidness of dug wells represents the intensive of groundwater used in the centre and the east of Semarang which is corresponding to the population density.

4. Results and Discussions

4.1. Groundwater level

Dug wells in coastal plains and lowlands of Semarang were utilized for daily need. Groundwater was exploited from an unconfined aquifer. Based on the hydrogeological mapping, the minimum and maximum of groundwater depth are 0.03 m and 17.5 m respectively (Figure. 4a). Following the topography elevation, the minimum depth was found in the north to the east of Semarang i.e. Genuk Sub-District, Semarang Utara Sub-District, and Semarang Timur Sub-District. Water table depth was below 2 m. Meanwhile, the water table depth in the centre (Semarang Tengah Sub-District and Gayamsari Sub-District), the South (Semarang Selatan Sub-District and Pedurungan Sub-District), and the west of Semarang (Semarang Barat Sub-District and Tugu Sub-District) was around from 2 to 17.5 m. The maximum depth was found in Wonosari (Tugu Sub-District). Groundwater flowed from the south to the north of Semarang while groundwater levels (water table) were around 40 to below 1 meter sea level datum (Figure. 4b).

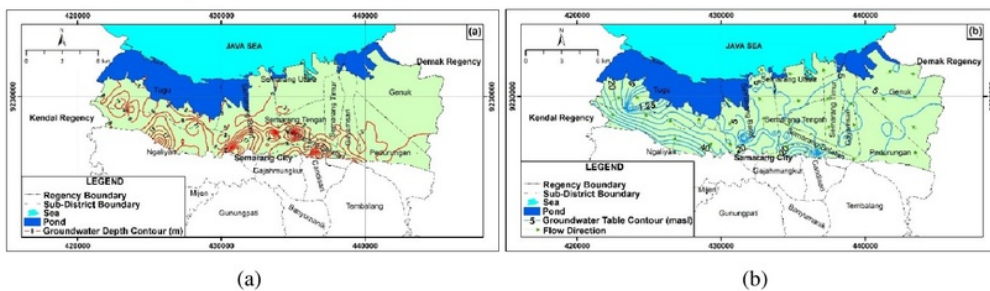


Figure. 4. Groundwater depth (a), and groundwater level and its directions (b). Groundwater depth in unconfined aquifer is following topographic, higher in the south and groundwater flows from the south to the north of Semarang

4.2. Hydrochemistry

The hydrochemical composition of the dug well water samples was analysed, and the results were presented in average values as displayed in Table 1. The results showed that the maximum eC value (6,370 $\mu\text{S}/\text{cm}$) was located in Trimulyo Village (Genuk Sub-District). It was around 3 km from the Java Sea coastline in the northeast of Semarang. Groundwater in this region indicated unsuitable for drinking water. Water has a taste (salty) and indicates there was sea water intrusion coming in this region. Indeed, the values of Na^+ and Cl^- were around 131 mg/L and 717 mg/L respectively. Obviously, those were higher than another region. Another indication of sea water intrusion in this region was the value of Salinity which was up to 3,600 mg/L. In the north of Semarang, eC values resulted above 2,000 $\mu\text{S}/\text{cm}$. While in the centre of Semarang, the range of eC values was 750-1,500 $\mu\text{S}/\text{cm}$ (Figure. 5). In this region, groundwater from dug wells was still possible for consuming within deep processing such as filtering, boiling, etc. In the west of Semarang, the eC values were high in the regions which were located nearby the ponds, while in the south the eC values were lower than in the north around 750-1,000 $\mu\text{S}/\text{cm}$.

The pH values of the water in coastal plains and lowlands of Semarang were mostly neutral around 6.5-8.2. According to WHO (2011), they were in desirable ranges for pH in water-drinking quality [14]. Although pH usually was no direct impact on water consumers, it was one of the most fundamental operational water-quality parameters. The lower the pH caused, the higher of corrosion level.

Table 1. Summary statistics of major ions content in the groundwater of Semarang coastal plains and lowlands

Variable	eC ($\mu\text{S}/\text{cm}$)	pH	DO (mg/L)	Salinity (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Cl^- (mg/L)	HCO_3^{-1} (mg/L)	SO_4^{-2} (mg/L)
Min	379	6.5	0.06	100	34.5	15.7	36.9	5.2	37	298	34.0
Ave	1,252	7.2	0.53	594	85.8	29.0	57.7	8.04	221	418	95.3
Max	6,370	8.2	1.50	3,600	131	50.0	85.2	11.8	717	534	310
SD	749	0.25	0.35	457	34.7	12.1	18.0	2.49	247	86.0	99.3

Note : Min: Minimum;

Ave: Average;

Max: Maximum,

SD: Standard Deviation

The highest and lowest of DO values were 1.5 and 0.06 mg/L respectively. The dissolved oxygen content of water was influenced by the source, temperature of water, treatment and chemical or biological processes taking place in the distribution system [14]. In the north and northeast of Semarang where the eC and Salinity values were high, the DO values were low 0.06-1.0 mg/L. Contrary, in the west of Semarang, the DO values were higher than those regions up to 1.5 mg/L.

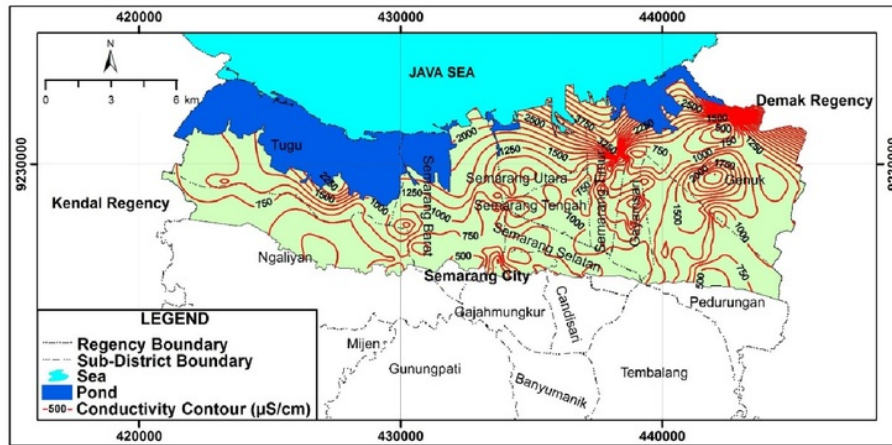


Figure 5. The electrical conductivity of coastal plains and lowlands of Semarang. In the north and north-east of Semarang show higher values of eC than another region.

To demonstrate the change of composition of water, a Stiff diagram (Figure. 6) showed the dominant cations and anions with concentration represented in electrical equivalent (meq / L). The major cations concentration in groundwater were in the decreasing order as $Na^{+1} > Ca^{+2} > K^{+1} > Mg^{+2}$. The major anions concentration were in the decreasing order as $HCO_3^{-1} > Cl^{-1} > SO_4^{-2}$. Sodium (Na^{+1}) was predominant cation in the east (SG-314) and north of Semarang (SG-142) while the chloride was the predominant anion in those areas. Chlorides were leached from various rocks into soil and water by weathering. The chloride ion concentration in Semarang was also influenced by seawater intrusion in coastal plains. It can be concluded that the most predominant water type in the east and the north of Semarang areas was the Na-Cl water type. While Ca^{2+} was distributed predominant cation of the groundwater samples in the south of Semarang (SG-139, SG-149, SG-198, SG-240). While HCO_3^{-1} was the predominant anion in the south of Semarang. It means that the most predominant water type in the south of Semarang was Ca- HCO_3 water type. Ca^{2+} ion was noted in Damar Formation which was contained by sedimentary rocks such as tuffaceous sandstone, conglomerate, and volcanic breccia. HCO_3^{-1} ion in Semarang was mainly derived from CO_2 present in the atmosphere.

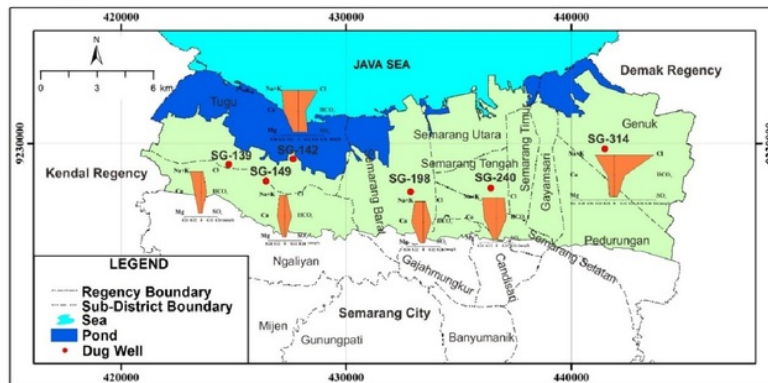


Figure 6. A plot of the Stiff diagram on the map in the coastal plains and lowlands of Semarang. Na-Cl water type is predominant in the north and east of Semarang (SG-142 and SG-314) while Ca- HCO_3 water type is predominant water type in the south (SG-139, SG-149, SG-198, SG-240).

To identify the groundwater facies, the Piper diagram [8] showed the electrical equivalent percentage (meq %) composition of different ions. Hydrochemical facies on the Piper diagram were conducted to determine the water type [4]. The Piper diagram provided in three parts: two trilinear diagrams along the bottom and one diamond-shaped diagram in the middle. The trilinear diagrams showed the percentage concentration of cations ($\text{Na}^+ + \text{K}^+$, Ca^{+2} , Mg^{+2}) and anions (HCO_3^{-1} , Cl^{-1} , SO_4^{-2}) in each sample. The data points of the two trilinear diagrams were projected onto a diamond-shaped which lied perpendicular to the third axis in each triangle. According to the Piper diagram (Figure. 7), there were two groups: alkaline water predominantly chloride (SG-142, and SG-314), and alkaline earth water with higher alkaline content predominantly hydrogencarbonate (SG-139, SG-149, SG-198, and SG-240).

According to the actual assessment of groundwater quality data, as explained above, the groundwater conservation zones in the coastal plains and lowlands of Semarang are developed to achieve sustainable development in groundwater management of unconfined aquifer based on the eC value [2]. There are four conservation zones: secure, vulnerable, critical, and damage (Figure. 8). The characteristics of hydrochemistry for each zone are represented in Table 2. The secure area spreads mainly in the south of Semarang (Ngalian and Semarang Selatan), locally in the east (Pedurungan and Genuk) and the centre (Semarang Tengah). Land used in this zone is dominant forest, plantation, and residence with the dense of population low to moderate. Groundwater used in this zone has less impact on groundwater quality in general. The existence of industrial and residential zones which have the population density of the moderate to very dense is causing groundwater to be vulnerable to contamination both in the vulnerable and critical zones in the north and the east of Semarang. Moreover, groundwater is unsuitable for water-drinking quality due to seawater intrusion in the damage area.

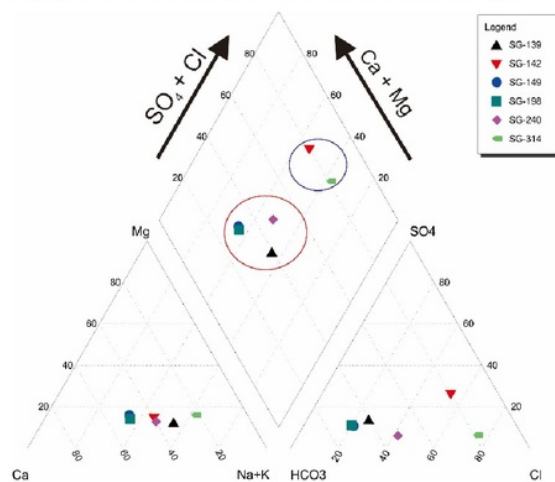


Figure 7. Piper diagram. Red circle shows the alkaline earth water with the higher alkaline content predominantly hydrogencarbonate group. Blue circle indicates alkaline water predominantly chloride group.

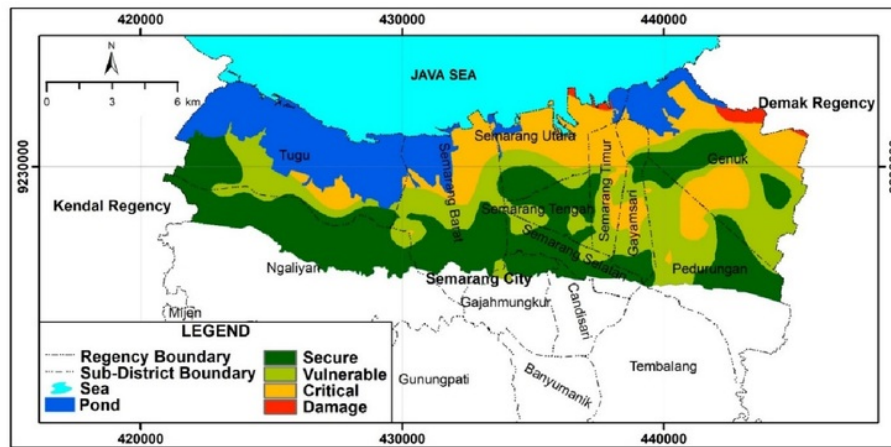


Figure 8. Groundwater conservation zone of unconfined aquifer in the coastal plains and lowlands of Semarang.

Table 2. Characteristics of groundwater conservation zone in the coastal plains and lowlands of Semarang.

Zone	eC ($\mu\text{S}/\text{cm}$)	Salinity (mg/L)	pH	DO (mg/L)	Groundwater depth (m)
Secure	<1,000	<300	6.5-8.2	0.06-1.50	0.03-17.5
Vulnerable	1,000-1,500	300-750	6.5-7.7	0.07-1.41	0.03-9.80
Critical	1,500-5,000	750-2,700	6.9-7.7	0.06-1.11	0.24-2.76
Damage	>5,000	2,700-3,600	6.9-7.2	0.26-0.80	0.21-1.04

5. Conclusions

Groundwater quality of unconfined aquifer that abstracts groundwater via dug well in Semarang coastal areas is investigated and assessed. Following the topography, the water table is lower in the north, and higher in the south and groundwater flows from the south to the north. The physical and chemical parameters of the samples that in the north and the east of the coastal plains and lowlands of Semarang show a higher value than in the centre and the south. EC and Salinity values have a range 1,500-6,370 $\mu\text{S}/\text{cm}$ and 750-3,600 mg/L respectively. Based on the cations and anions concentration, there is two water type which is Na-Cl water type and Ca- HCO_3 water type. In the east and the north of Semarang areas are the Na-Cl water type while the most predominant water type in the south of Semarang is Ca- HCO_3 water type. The groundwater conservation zone is developed based on hydrochemistry value (eC) to achieve sustainable development in groundwater management of unconfined aquifer. There are four conservation zones: secure, vulnerable, critical, and damage.

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