Groundwater Quality Analysis to Determine Groundwater Facies in Pati-Rembang Groundwater Basin

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Abstract. Pati-Rembang Groundwater Basin is located in Pati Regency, Rembang Regency, and Jepara Regency. Industrial growth and groundwater utilisation increase every year in line with increasing population. Hence, it is necessary to evaluate the quality of groundwater both in unconfined aquifer and confined aquifer as drinking water and irrigation as well as to define groundwater facies as the goals of the research. The methods of groundwater quality evaluation are hydrogeological mapping to determine the geological surface condition, measuring water table of unconfined aquifer and confined aquifer, conducting a hydrogeochemistry analysis of 50 groundwater samples. The results showed that Pati-Rembang groundwater basin consists of 5 lithology units, i.e. Sandy tuff, Andesite Porfiri Lava, Tuff, Volcanic Andesite, and Alluvial Deposit. Groundwater in the unconfined aquifer flows from the west to the north, to the east, and the south. The confined aquifer flows from the west to the centre, and the north. There are five groundwater facies in the unconfined aquifer while in the confined aquifer consist of three facies. Magnesium bicarbonate dominates both of the unconfined aquifer and confined aquifer. Calculation of water quality index both unconfined aquifer and confined aquifer showed that groundwater is still suitable for drinking water.

1. Introduction
Pati-Rembang Groundwater Basin is a cross-regency groundwater basin which is located in Pati Regency, Rembang Regency, and Jepara Regency with a total area approximately 102,800 Ha. The basin is shown in Figure 1. Population increase provides enormous stress on people’s need for clean water for various purposes will increase as well.

Pati-Rembang Groundwater Basin is composed of various types of rocks. The different rock types indicate the different process of changing groundwater hydrochemical composition when groundwater flows and interacts with the rock it passes through. Groundwater aquifer systems have a dynamic characteristic, easily influenced by infiltration of meteoric water, susceptible to human activity particularly in the use of chemical both for agriculture and industry, and its properties are strongly affected by the condition of the current season makes the needs for research to utilise different aquifer zone from each other more appropriately used.

The research was intended to identify the groundwater facies, to evaluate groundwater quality, to calculate the Water Quality Index (WQI), and to calculate the ratio of Sodium (Na+) ion toward Calcium (Ca2+) and Magnesium (Mg2+) ions (SAR) in the Pati-Rembang Groundwater Basin.

The research was conducted by analysing of hydrogeochemistry of the unconfined aquifer, and confined aquifer in Pati-Rembang Groundwater Basin concerning the standard requirement for drinking water from The Indonesian Ministry of Health.
2. **Regional Geology and Hydrogeology setting**

Pati-Rembang Groundwater Basin is included in two sheets of a geological map; they are The Regional Geological Map of Kudus and Rembang Sheet. Based on Regional Geological Map of Rembang Sheet [1] and Kudus Sheet [2], the geological condition of Pati-Rembang Groundwater Basin has dominated by rocks which is resulted from sedimentary activity and volcanism of Muria Mountain. Lithostratigraphically, various types of rock forming the research area can be grouped into several units of rocks and mentioned from the young to the old can be seen in Figure 2. The formations from the oldest are Patiayam Formation (Tpp), Quaternary Genuk Mountain Volcanic Formation (Qvg), Quaternary Muria Mountain Tuff Formation (Qvtm), Quaternary Muria Mountain Lava Formation (Qvlm), and alluvium deposits (Qa). Quaternary Muria Mountain Tuff Formation is located in the west to the centre part of the research area. Meanwhile, alluvium (Qa) spread along in the Java Sea area to the centre and the east. They consist of gravel, sand, silt and clay.

Based on the rock type formation which is concerned with the capability to store or to flow the water, there are three aquifer systems in Pati-Rembang Groundwater Basin. The first aquifer is aquifer which flows through intergranular. It is represented by shallowing water table. This aquifer consists of alluvial plain which are deposits mainly composed of sand, gravel, silt and clay also eruption rock of tuff. This aquifer can be distinguished into three types, wide spread-high productivity aquifer, local aquifer with moderate productivity level, and wide spread-moderate productivity aquifer. Other type is aquifer with flow through cracks and intergranular. This aquifer consists of lithology as result of volcanic activity such as tuff. This aquifer can be distinguished into two types they are wide spread-moderate productivity aquifer and local aquifer and productive. The last aquifer zone is less productive aquifer zone and rare groundwater flow with flow through intergranular and fractures. This aquifer is composed by volcanic rocks of lava and generally deep groundwater level.
3. Research Methods

The methods used were hydrogeological mapping and hydrogeochemistry analysis of 50 groundwater samples which were 35 samples of unconfined aquifer and 15 samples of the confined aquifer.

Groundwater facies were the identification of groundwater types based on the differences and water forming that related to a system and its availability [3] using the Piper Diagram. In interpreting the groundwater facies, the ions used were the main ions of groundwater constituent both anions and cations. Cation ions are positive ion charge that consist of calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), sodium (Na$^+$), and potassium (K$^+$). Anion ions are negative ion charge which consists of chloride (Cl$^-$), sulfide (SO$_4^{2-}$), bicarbonate (HCO$_3^-$).

The standard used for drinking water in Indonesia is regulated based on the regulation [4]. To evaluate groundwater used as drinking water can be conducted by weighting groundwater quality based on Water Quality Index (WQI) which each parameter based on the most fundamental problems and refers to the standard limits set by the Ministry of Health of the Indonesian Republic as shown in Table 1. This weighting is based on the influence of specific chemical or ionic properties in all of the groundwater samples [5] and the effect on human’s health.

Groundwater in Pati-Rembang Groundwater Basin also is utilised by people for irrigation using the unconfined aquifer. Therefore, an evaluation is required to find out the feasibility of unconfined aquifer by using the Sodium Absorption Ratio (SAR) and electrical conductivity. SAR value can be obtained with equation 1 [6] as follows

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$  \\

SAR is the ratio of sodium ion (Na$^+$) toward calcium ion (Ca$^{2+}$) and magnesium ion (Mg$^{2+}$) in meq/L which is plotted in Wilcox diagram to understand the groundwater class for the irrigation.

Furthermore, the results of the laboratory test of water samples were analysed to obtain the groundwater quality value for drinking water or Water Quality Index (WQI) [4]. Firstly, parameter and weighting were calculated on each parameter. Determining parameter and weighting were have no reference as each water analysed has influence level of a hydrochemical parameter varying between one area to another. Unconfined aquifer and confined aquifer of the research area have different weighting value from one to another because based on laboratory test result obtained two different dominant influences from each aquifer. Parameter from each aquifer can be shown in Table 1.
### Table 1. The relative weight of chemical parameter confined aquifer.

| Chemical Parameter | Permenkes No.492/MENKES/PER/IV/2010 | Weight ($w_i$) | Relative Weight ($W_i$) |
|--------------------|-------------------------------------|----------------|-------------------------|
| Fe$^{3+}$ (mg/L)   | 15.0                                | 2              | 0.13                    |
| SO$_4^{2-}$ (mg/L) | 250                                 | 2              | 0.13                    |
| Na$^+$ (mg/L)      | 200                                 | 3              | 0.2                     |
| Cl$^-$ (mg/L)      | 250                                 | 3              | 0.2                     |
| TDS (mg/L)         | 500                                 | 4              | 0.27                    |
| Hardness (mg/L)    | 500                                 | 1              | 0.07                    |

$\sum w_i = 15 \quad \sum w_i = 1.0$

After conducted $W_i$ (relative weight) value as a result of weighing process with Eq. 2, can conduct a measurement of $q_i$ (rating scale quality) by comparing parameter value ($C_i$) with standard value ($s_i$) then next multiplied with 100, as shown in Eq. 3. The next step was to sum up $W_i$ value and $q_i$ to obtain sub index ($SI$) value from each parameter as in Eq. 4. After getting the value of $SI$ from all of the parameters, the WQI value can be obtained from counting all the SI parameters like in Eq. 5. After getting the WQI value, the value is grouped into WQI classification with [4], to determine the groundwater samples were feasible or unfeasible for drinking.

$$Wi = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (2)$$

$$q_i = \frac{C_i}{s_i} \times 100 \quad (3)$$

$$SI = Wi \times q_i \quad (4)$$

$$WQI = \sum SI \quad (5)$$

### 4. Results and Discussion

#### 4.1 Point Observation Station and Groundwater Surface

There are about 205 points of observation station in the research area with details of 133 dug wells, ten springs, and 62 points of deep wells. From 205 observation points, there are 50 samples which represented of groundwater samples taken for laboratory testing at Geological Agency in Bandung. Thirty-five samples were taken from the unconfined aquifer (dug wells and springs) and fifteen samples of the confined aquifer (deep wells).

Groundwater of unconfined aquifer in Pati-Rembang Groundwater Basin flow from the very steep hill morphology of the peak of Muria mountain and its surroundings, with discharge into the Java Sea. It illustrates that the morphological influence on groundwater flow of unconfined aquifer from the higher in the west to the lower areas in the north (Figure 3a). For the flow pattern and its direction of a confined aquifer, groundwater is slightly different with the unconfined aquifer. In the eastern part, the confined aquifer flows from the east to the centre as shown in Figure 3b.

#### 4.2 Groundwater Facies

Based on the plots result on Piper diagram, the groundwater facies in the unconfined aquifer consists of different facies (Figure 3a). Groundwater samples are spread into five facies with the most dominant facies is magnesium bicarbonate. Bicarbonate ions (HCO$_3^-$) describes that the origin of groundwater comes from rain or meteoric water. Magnesium ion shows that groundwater passes through the igneous rock in the recharge zone as shown in sample MA-1 that has lithology of volcanic breccia and lava flow. Indeed, some samples which are SG-17 in Magersari Village Rembang District,
SG-32 in Sambiyan Village Kaliori district, dan SG 121 in Bajumulyo Village Juwana district, indicated to be affected by seawater. They are classified into Sodium Chloride facies.

Figure 3. Map of groundwater flow in the unconfined aquifer (a) and confined aquifer (b) of Pati-Rembang groundwater basin.

Figure 4. Hydrochemical facies of unconfined aquifer (a) and confined aquifer samples (b) in Piper diagram.

The confined aquifer samples conducted three facies (Figure 4a) which mainly contains magnesium bicarbonate ions while some samples (SB-41 in Winong district and SB-53 in Gabus district) indicated to be affected by seawater and classified into sodium chloride facies.

The availability of $\text{Ca}^{2+}$ ion in groundwater comes from igneous rock especially containing minerals of silicate, pyroxene, amphibole, and feldspar. Moreover, the calcium also can be found on mineral in sedimentary rock associated with sulphate, gypsum, and anhydrite. The anion of $\text{HCO}_3^-$ exists in the groundwater that comes from rainwater or meteoric water which is precipitated to the ground. $\text{HCO}_3^-$ is dissolved of CO$_2$ in rainwater to the ground [7].
4.3 Groundwater Quality Index (WQI)

WQI is an analysis method of water quality by calculating a weighting of hydrochemical parameters which tend to influence groundwater quality. It will be then evaluated based on certain standards related to the quality of drinking water.

From the result of WQI calculation on 35 groundwater samples of unconfined aquifer using [4], conducted that the minimum value of WQI is 7.75 and the maximum value is 447.43 with an average value of 88.64. About 51% groundwater samples are grouped into very well quality, 23% are grouped into well quality, 14% are poor quality, 3% are very poor quality, and 9% is unfeasible for drinking. The high value of WQI is around Kaliori district which indicates water quality is not suitable if it is used for drinking water. Groundwater in this area has undergone a salty taste change due to the influence of seawater which proved by the high concentration of Cl⁻ ion in this area.

The distribution map of groundwater quality of unconfined aquifer (Figure 5a) and confined aquifer (Figure 5b) based on WQI classification.

Figure 5. Groundwater quality map for drinking water of unconfined aquifer (a) and confined aquifer (b) of Pati-Rembang groundwater basin.

In a confined aquifer, the highest weight, 4, is given to the TDS parameter while the lowest weight, 2, is Fe³⁺, SO₄²⁻, and salinity. In this research, a parameter that used to evaluate the groundwater refers to [4]. Based on the result of WQI calculation conducted the minimum value of WQI is 9.36, and the maximum is 216.3 with the average value is 60.75. About 60% of the groundwater sample grouped into very well quality. While 20% are in good quality, and 13% are grouped into poor quality, and the rest, 7%, is in very poor.

4.4 Groundwater Quality for Irrigation

Groundwater for irrigation purposes generally uses surface water or groundwater of unconfined aquifer. Groundwater for irrigation can be determined based on SAR and electrical conductivity values. SAR (Sodium Absorption Ratio) is the ratio calculation of sodium (Na⁺) ion towards calcium (Ca²⁺) ion and magnesium (Mg²⁺) ion in every milliequivalent per litre (meq/L). Based on the calculation of SAR, the lowest value is 0.87, and the highest reached 19.98 with the average value is
4.44. Based on the classification [6], 89% are very good category, 8% are in good quality for irrigation, and the rest, 3%, is fair for irrigation.

The result of Wilcox diagram analysis (Figure 6) shows eight different classes. Class C1-S1, class C2–S1, class C2-S2 are groundwater class that can be utilised for irrigation. Class C3–S1 and class C3-S2 also includes to the water can be utilised for irrigation, but not to be recommended using the water for irrigation because it has a high salinity condition. Class C4-S2, class C4-S3 and C4-S4 are not recommended for irrigation because this water has a high salinity condition and sodium composition condition that will inhibit plant growth.

![Figure 6. Groundwater classes for irrigation of unconfined aquifer based on Wilcox diagram [8].](image)

5. Conclusion
The research area has surface lithology such as tuff sandstone, volcanic breccia, tuff, andesite porfır lava, and alluvial deposit. Groundwater facies of unconfined aquifer in the research area is divided into five facies, i.e. Sodium chloride, Calcium chloride, Sodium Bicarbonate, Magnesium Bicarbonate, dan Mixing with the most dominant facies is Magnesium Bikarbonat Facies. Indeed, the confined aquifer are divided into three facies, i.e. Sodium chloride, Magnesium bicarbonate, dan mixing with the most dominant facies is Magnesium Bicarbonate.

From the WQI measurement result, generally unconfined aquifer in the research area is still considered feasible for consumption which has various classes, from very well to unfeasible for drinking. High WQI value is located in around Kaliori district which indicates very poor water quality. Indeed, the samples of the confined aquifer have various classes, from very well class until very poor. The highest WQI value in the confined aquifer is situated in Winong district which indicates very poor water quality. Based on SAR value, 89% samples of the unconfined aquifer are very well, while 8% and 3% of samples are in good and fair classes respectively.
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