Groundwater flow patterns and hydrochemical facies of Kendal groundwater basin, Central Java Province, Indonesia

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Abstract. Information on groundwater flow patterns is very important in groundwater conservation efforts. The patterns of groundwater flow will also affect the groundwater chemistry. However, information on this issue in some areas is often neglected or not yet available such as in Kendal district, Central Java Province, Indonesia. This paper presents the groundwater investigations in the Kendal groundwater basin area of Kendal district. The investigations cover geological survey, including 114 points of observation and measurements of shallow wells and deep wells. Groundwater sampling also carried out at 15 points that distributed evenly for groundwater chemical analysis. The results showed that the groundwater flow patterns in Kendal are generally flowed from south to north direction, for both the unconfined aquifer and confined aquifer. Based on the trilinear piper diagram, the groundwater facies for unconfined aquifer consists of magnesium bicarbonate, calcium chloride and mixed types. Whereas in the confined aquifer, the results obtained are of sodium chloride, calcium chloride and mixed types. Some similarities of groundwater facies found between the unconfined aquifer and confined aquifer, indicating an interaction of both aquifers. In addition, ion enrichment from the recharge area to the discharge area found due to the interaction of groundwater with aquifer material based on the stiff diagrams.

1. Introduction

Human needs for water are increasing as the population increases in the world. This water need can be supported from either surface water or groundwater or a combination of both. In general, the quality and quantity of groundwater are better than surface water [1]. Determination of groundwater hydrochemical origins is important in water management including the protection, conservation and sustainability of groundwater resources [2][3]. Recent studies show that the composition of groundwater hydrochemical is able to help define groundwater flow patterns in the aquifers [4]. This information is very important in groundwater systems, especially those consisting of multilayer aquifers and will be very helpful in understanding the interaction of groundwater among aquifers [5]. In addition, the quality of groundwater will be influence by the chemical composition of groundwater [1]. In Kendal groundwater basin of Central Java Province Indonesia, groundwater is the main source in providing the water needs for people. Recently, the groundwater flow patterns and groundwater hydrochemical facies in Kendal district has not been studied and reported in detail. Therefore, this
study aims to determine the flow patterns of groundwater and groundwater facies in Kendal groundwater basin. The area of Kendal groundwater basin covers a large part of Kendal district with an area of approximately 393 km$^2$ as shown in Figure 1 [6]. Geographically, Kendal groundwater basin is bordered by the Java Sea to the north and Kuto River to the west. The southern boundary is clay deposits from the Kerek Formation which is no flow boundary. The eastern boundary is bounded by Muara Sidempel in the north which continues to the south at the upper reaches of the Blorong River in Darupono Village.

Figure 1. Research area of Kendal groundwater basin and location of observation wells

2. Methodology

This study consists of a preparation process, fieldwork, data analysis and reporting. Preparation phase included tool preparation, administrative work and secondary data collection. The equipment used for the survey was a hammer, compass, GPS, roll meter and groundwater sample bottle. The field work phase includes geomorphological observation, geological observation, groundwater data collection and groundwater sampling [7][8]. Groundwater measurement and observation were carried out on 73 shallow wells and 41 deep wells. Locations of groundwater measurement and sampling in the field are shown in Figure 1. Fifteen groundwater samples were taken from the field consisting of 7 samples from unconfined aquifers and 8 samples from confined aquifers, as shown in Figure 1, according to Indonesia National Standard [9]. The groundwater samples were analysed for the major ion contents such as Na$^+$, K$^+$, Ca$^{2+}$, Mg$^{2+}$, Cl$^-$, CO$_3^{2-}$, HCO$_3^-$, and SO$_4^{2-}$ referring to the Indonesian National Standard from National Standardization Agency of Indonesia (BSN) were graphically interpreted by Schoeller, Trilinear Piper and Gibbs diagrams to show the groundwater facies in Kendal groundwater basin [10].

3. Result and Discussions

3.1. Hydrogeology

The elevation of the study area in Kendal ranged from 0 to 275 meters above sea water level with slopes varied between 0° – 50°. The geomorphology unit of this area is divided into 3 units, namely coastal plain units, alluvial plain units, and hills units [11]. The coastal plain is located in the north, the alluvial plain lies in the middle area, and the hills in the southern part of the research area. Based on its
regional geological map, the study area is composed of two formations, namely alluvium deposits and Damar Formations [12]. Based on the results of field observations, the lithology can be divided into four different lithology units, namely sand sediment units, silt-clay sediment units and the intercalation of breccia-sandstone units (Figure 2). Sand and sandstone have high porosity and permeability, which is a good layer for an aquifer [13]. Silt has a medium porosity and permeability, however, can be categorized as an aquitard. Meanwhile, clay and breccia are impermeable layers. Based on well log data, groundwater depth and geo-electrical data (Figure 3), the study area can be divided into two types of aquifers, namely unconfined aquifers and confined aquifers. Unconfined aquifers are dominated by silt-sand, while confined aquifers are composed of silt, sand and sandstone. Based on geo-electrical data, the thickness of unconfined aquifers in the alluvial plain is about 7 meters; the hilly area to the southeast is between 16-20 meters and in the south-western hills approximately 6 meters [14]. While the thickness of confined aquifers varies greatly between 5-80 meters.

![Geological map of Kendal groundwater basin](image)

**Figure 2.** Geological map of Kendal groundwater basin

3.2. Groundwater flow patterns
Groundwater in the study area flows from the south towards the north, both for unconfined aquifers and confined aquifers, as shown in Figure 4. The groundwater flow patterns of unconfined aquifer follow the topographic pattern, however for confined aquifer; the patterns are more controlled by the spreading of aquifer layer both vertically and horizontally. The dominant sand deposits on the west side of the study area (cross section A-B and A-C in Figure 3) cause the direction of groundwater flow of confined aquifer to be concentrated in this area.

3.3. Hydrochemical of groundwater
The results of groundwater chemical analysis of 15 samples from unconfined aquifer (SG) and confined aquifer (SB) are shown in Table 1. All the samples have reaction error of chemical analysis of less than 20%. The pH of groundwater in confined aquifers is higher than the pH of unconfined aquifers. This is because the groundwater that flowing in the confined aquifer gets less CO₂ from the atmosphere than unconfined aquifer. The reaction between H₂O and CO₂ will produce H₂CO₃, where the carbonic acid will split into HCO₃⁻ and H⁺. The less CO₂ in groundwater, the pH will be more alkaline. This was also confirmed with HCO₃⁻ concentration in confined aquifer is lower than unconfined aquifer as shown in Table 1. The average value of total dissolved solids (TDS) in unconfined aquifer is higher than confined aquifer. Higher TDS in the unconfined aquifer probably
due to more acidic pH causing more ions dissolve in groundwater from the aquifer materials [15]. Groundwater samples from confined aquifers have an average nitrate content of 0.3 mg/L which is much lower than the unconfined aquifer of 15.8 mg/L. The source of nitrate mostly comes from surface contamination such as septic tanks, agricultural fertilizers and livestock and human waste [16]. Therefore, groundwater in the unconfined aquifer is more easily polluted than groundwater in confined aquifers.

![Figure 3. Cross section of geology based on geo-electrical data](image)

![Figure 4. Groundwater flow map of unconfined aquifer (a); and confined aquifer (b)](image)
Table 1. Geochemical composition of groundwater

| No. | Sample Code | Coordinate X | Coordinate Y | pH  | TDS (mg/L) | Na⁺ (mg/L) | K⁺ (mg/L) | Ca²⁺ (mg/L) | Mg²⁺ (mg/L) | Cl⁻ (mg/L) | SO₄²⁻ (mg/L) | HCO₃⁻ (mg/L) | NO₃⁻ (mg/L) |
|-----|-------------|--------------|--------------|-----|------------|------------|-----------|-------------|-------------|------------|-------------|-------------|-----------|
| 1   | SB 1        | 404422       | 9233237      | 8.6| 200        | 84.2       | 27.8      | 8.0         | 4.9         | 151.5      | 37.1        | 55.7       | 0.0       |
| 2   | SB 4        | 411155       | 9237168      | 7.9| 288        | 84.2       | 27.8      | 18.4        | 11.1        | 151.5      | 37.1        | 55.7       | 0.0       |
| 3   | SB 5        | 416778       | 9231013      | 7.9| 310        | 38.8       | 16.1      | 73.8        | 39.0        | 67.5       | 8.0         | 12.0       | 0.0       |
| 4   | SB 6        | 418388       | 9225062      | 8.0| 292        | 85.2       | 21.8      | 32.9        | 17.8        | 37.5       | 10.1        | 15.2       | 0.0       |
| 5   | SB 7        | 412109       | 9222492      | 7.1| 142        | 18.5       | 10.2      | 37.7        | 22.4        | 28.5       | 3.7         | 5.5        | 0.0       |
| 6   | SB 10       | 407006       | 9232846      | 8.4| 251        | 51.3       | 11.8      | 39.3        | 22.5        | 96.0       | 51.8        | 131.8      | 0.0       |
| 7   | SB 15       | 395201       | 9235115      | 7.8| 635        | 153.6      | 16.8      | 44.9        | 27.5        | 269.9      | 40.7        | 159.7      | 2.1       |
|     | An average  |              |              | 8.0| 302.6      | 73.7       | 18.9      | 36.4        | 20.7        | 114.6      | 26.9        | 62.2       | 0.3       |
| 8   | SG 1        | 404422       | 9233237      | 7.9| 267        | 52.5       | 16.4      | 46.5        | 28.6        | 37.5       | 55.8        | 159.7      | 4.9       |
| 9   | SG 2        | 411016       | 9238967      | 7.5| 633        | 85.7       | 6.6       | 139.5       | 71.1        | 34.5       | 50.0        | 226.1      | 16.1      |
| 10  | SG 6        | 418088       | 9227634      | 6.1| 175        | 32.1       | 25.7      | 34.5        | 20.8        | 22.5       | 10.1        | 54.9       | 61.2      |
| 11  | SG 7        | 411759       | 9222989      | 7.6| 215        | 13.7       | 11.0      | 60.9        | 32.3        | 57.0       | 12.8        | 151.9      | 0.0       |
| 12  | SG 8        | 407276       | 9225855      | 7.6| 485        | 61.6       | 49.2      | 195.9       | 61.8        | 123.0      | 61.3        | 311.2      | 3.3       |
| 13  | SG 9        | 412767       | 9232123      | 7.5| 751        | 54.8       | 43.8      | 135.5       | 68.2        | 269.9      | 15.9        | 98.8       | 5.5       |
| 14  | SG 12       | 397248       | 9227634      | 6.9| 287        | 41.1       | 17.7      | 65.8        | 35.5        | 90.0       | 48.2        | 135.5      | 0.0       |
| 15  | SG 13       | 395200       | 9233067      | 7.3| 142        | 25.3       | 19.1      | 64.2        | 39.3        | 73.5       | 11.6        | 206.8      | 24.8      |
|     | An average  |              |              | 7.2| 384.0      | 44.9       | 24.7      | 102.3       | 47.0        | 95.8       | 30.0        | 169.3      | 15.8      |

Note: SB: confined aquifer; SG: unconfined aquifer

3.4. Hydrogeochemical facies
The Schoeller diagram [17] showed a difference of chemical composition of groundwater from unconfined aquifer and confined aquifer, as shown in Figure 5. Most of groundwater from unconfined aquifer samples has higher Ca²⁺ and Mg²⁺ concentrations than confined aquifer. It means that the unconfined aquifer groundwater is more hardness than confined aquifer. Those ions enter to unconfined aquifer by leaching from minerals within an aquifer due to lower pH. Common calcium-containing minerals are calcite, gypsum and anorthite. Sodium (Na) is dominant in the confined aquifer due to increase of clay-rich material dispersed in the aquifer [18]. In addition, an average Cl⁻ ion is also higher in confined aquifer than unconfined aquifer. High concentrations of Na and Cl⁻ ions in the confined aquifer are probably due to leaching of halite (NaCl) mineral in the aquifer materials.

Figure 5. Schoeller diagram of groundwater sample in the research area
The majority of groundwater samples from unconfined aquifer is dominated by magnesium bicarbonate facies (6 samples), calcium chloride facies (1 sample) and mixed facies (1 sample). Four samples from confined aquifer belong to sodium chloride facies and followed by calcium chloride (2 samples) and mixed facies (1 sample), as shown in Figure 6 and Figure 7. Calcium chloride and mixed facies were found in unconfined and confined aquifers indicate that groundwater in both aquifers interact especially in the alluvial plain.

![Figure 6. Trilinear piper diagram of groundwater samples](image)

Stiff diagram is a graph in the form of a polygonal shape to show chemical composition of groundwater as shown in Figure 8 [19]. It shows that the unconfined aquifer has a similar pattern in recharge and discharge area, but found different in the transition zone. The stiff diagram pattern of confined aquifer is also similar to unconfined aquifer. Same patterns between recharge and discharge area of both aquifers indicate that the groundwater has the same system. Ion enrichment occurs during the process of groundwater movement from recharge area to discharge area due to reaction between water and aquifer materials. Stiff diagram patterns in transition regions, both unconfined and confined aquifers show the same pattern. This indicates that there is an interaction between unconfined and confined aquifers. The result is also in line with the groundwater facies interpretation.
Several parameters that control the groundwater chemistry are aquifer materials, bedrock mineralogy, rainfall intensity and quality of groundwater recharge. In order to understand natural mechanism of controlling groundwater chemistry, including the precipitation, rock-water interaction and evaporation, it can be developed a graph of TDS versus Na\(^+\)/Na\(^+\)+Ca\(^2+\) for cations and TDS versus Cl/(Cl+HCO\(_3^-\)) for anions [20]. All of groundwater samples of both unconfined and confined aquifers were plotted in Gibbs diagram as shown in Figure 9. It shows that all of the samples fell into group that may influenced by rock-water interaction dominance.

4. Conclusion
Hydrogeology of Kendal groundwater basin consists of unconfined and confined aquifer based on the type of lithology and their stratigraphy. Groundwater flow patterns in the basin show the flow direction from south to north for both the unconfined and confined aquifers. The sand layer is thick enough as a confined aquifer in the western region of the Kendal groundwater basin causing of groundwater flow concentrated in this area. Groundwater facies of unconfined aquifers consist of magnesium bicarbonate, calcium chloride and mixed types, while confined aquifer comprises of sodium chloride, calcium chloride and mixed types. Both aquifers have the same facies of calcium chloride and mixed types. This is indicating that both of them have groundwater interaction, especially in the alluvial plains. This also confirmed with stiff diagram result. During the process of groundwater movement from the recharge area to discharge area, there is an enrichment of major ions from dissolving of aquifer materials. This is also supported by the Gibbs diagram which shows that the dominant process of controlling groundwater chemical composition in the study area is the interaction between groundwater and aquifer materials. While the indication of groundwater pollution from
human activities is found in the unconfined aquifers where the presence of nitrate content is rather high compared to the confined aquifers. Therefore, in order to guarantee sustainable use of groundwater in this area, it is necessary to conserve groundwater, especially in the unconfined aquifer to protect from contamination by human activities.

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