Pattern and direction of groundwater flow and distribution of physical-chemical properties of groundwater in Randublatung basin

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Abstract. The people in the Randublatung basin (Grobogan, Blora, and Bojonegoro Regencies) using groundwater for daily needs and agriculture activity. As the initial step of basin-based groundwater management, it is necessary to understand the groundwater potential in this area: pattern and direction of groundwater flow and groundwater physical-chemical properties (pH, temperature, total dissolved solids, and electrical conductivity). This research aims to analyze the pattern and directions of groundwater flow, the physical-chemical properties, and the correlation between the two. This research method is field measurement of 45 different spots of dug wells in the Randublatung basin. Our results indicate that the pattern and direction of groundwater flow in the Randublatung basin are heading to Bengawan Solo River and then following the river's flow. The groundwater physical-chemical properties measured: pH value is 6.8 on average, the temperature is 28.9 °C on average, TDS concentration is 409 mg/L average, and electrical conductivity rate is 843 µS/cm average. There is no significant correlation between groundwater flow with pH value and groundwater temperature. However, groundwater TDS concentration and electrical conductivity rate in the Randublatung basin increase as groundwater flows to the Bengawan Solo River, which is affected by the minerals of aquifer rocks (alluvial deposits).

Keyword: groundwater flow, physical-chemical properties, Randublatung

1. Introduction
Groundwater is one of the water resources that are relatively easy to get and has a good quality. People using groundwater for daily needs and agriculture activity, for example, people of the Randublatung basin. The Randublatung basin is located in Grobogan, Blora, and Bojonegoro Regencies, with 206 km² of area. Potential groundwater capacity in the Randublatung basin for the unconfined aquifer is 23,000,000 m³/year and 9,000,000 m³/year in a confined aquifer [1]. The total population of Grobogan Regency in 2019 is 1,351,429 people, and the population growth rate is 0.56% [2]. Meanwhile, in the same year, the population of Blora Regency is 925,642 people, and the population growth rate is 1.02% [3]. Other than that, Bojonegoro Regency had 1,331,077 people in 2019 [4]. Population growth rate indicates an increase in daily activities and agriculture activities so that the use of groundwater will also increase.
Excessive groundwater use can cause various problems, such as groundwater level changes and land subsidence [5]. Basin-based groundwater management is necessary so that the Randublatung basin does not negatively impact excessive groundwater use. In basin-based groundwater management, the pattern and direction of groundwater flow and the physical-chemical properties of groundwater are included in the technical component, namely the evaluation of the potential of groundwater resources [6]. Therefore, it is essential to know the groundwater flow system and the distribution of physical-chemical properties of groundwater in the Randublatung basin as the first step of basin-based groundwater management.

In this research, we analyze the pattern and direction of groundwater flow and distribution of physical-chemical properties of groundwater using Geographic Information System (GIS). This method has been applied in many similar research, such as on Pekanbaru Regency, Indonesia in 2015 [7], Harare, Zimbabwe in 2019 [8], Kupang Regency, Indonesia in 2020 [9], Coimbatore, India in 2021 [10], Sistan and Baluchestan Province, Iran in 2021 [11]. This research aims to analyze the pattern and direction of groundwater flow and the distribution of physical-chemical properties of groundwater in the Randublatung basin. In addition, to analyze the relationship between pattern and direction of groundwater flow and the physical-chemical properties of groundwater. This research is expected to be an initial description of groundwater in the Randublatung basin.

2. Material Methods

2.1 Study area

The study area of this research is in Randublatung Basin. The basin's location is in Grobogan Regency, Blora Regency, and Bojonegoro Regency, as seen in Figure 1. [12] The location of Randublatung Basin physiologically is in the Depression Zone of Randublatung, which is between two hills. On the north side, there is Rembang Hills and on the south side is Kendeng Hills. So that from topography aspect, the elevation on the north side and the south side is from +100 m to +200 m. While the elevation in the Randublatung basin is about below +50 m to +100 m.

![Figure 1. The study area and the locations of measuring point with topography condition surroundings](image-url)
The geology of the Randublatung basin is shown in Figure 2. The formation of rocks from older to youngest in the Randublatung basin is Bulu Formation (Tmb), Wonocolo Formation (Tmw), Ledok Formation (Tml), Mundu Formation (Tpm), Lidah Formation (QTl), and Alluvial Deposits (Qa) [13]. The formation of rocks shows that there are marl and limestone on the bottom side of this basin and gradually turns into clay and sandstone on the upper side. Hydrogeological, formation of rocks that can become an aquifer is Lidah Formation (QTl) and Alluvial Deposits (Qa). Lidah Formation (QTl) consists of clay and sandy in some places. Meanwhile, Alluvial Deposits (Qa) consists of sandstone and gravel. So, there are two types of aquifers in the Randublatung basin, confined aquifer and unconfined aquifer [1].

![Figure 2. Regional Geology of Randublatung basin showing that the basin consists of alluvial deposits (Qa)](image)

Data from the water table is used for the pattern and direction of groundwater flow analysis. The physical-chemical properties of groundwater are directly measured on the field. Water table and physical-chemical properties were measured in 45 dug wells in the Randublatung basin. The dug wells that were measured are dug wells that were not exposed to rainwater directly.
2.2 Measuring water table
[14] The water table is needed to determine the direction of water flow. The direction of water flow can be obtained by measuring the water table from neighboring wells in meters above sea level (masl). Water table measurement can be performed only in an open well, such as dug wells.

Measuring the water table can be done by using measurement tapes. Figure 3 shows how to obtain the depth of the water table in masl. The first step is measuring water level depth from the edge of the well casing (AC). Then, measure the height of the well casing (AB). Depth of water table (BC) can be calculated from the subtraction of AC and AB. To obtain water table in masl, elevation data is needed. Subtraction between the elevation of ground level and depth of water table will produce water table in masl.

Figure 3. Measuring the depth of the water table (BC). AC is a depth of water table from well casing. AB is the height of the well casing. BC was obtained by subtraction of AC and AB [14].

2.3 Measurement of groundwater physical-chemical properties
The physical and chemical properties of groundwater can indicate the quality of groundwater [15]. The physical-chemical properties of groundwater in this research are pH, temperature, total dissolved solids (TDS), and electric conductivity. Value of pH shows groundwater's composition. Low pH values (below 4) indicate acid water that can dissolve metals in contact with water. Water with pH 7 means neutral water. High values of pH (above 8) indicate alkaline water. The temperature data of groundwater reflects its hydrological condition [14]. If the groundwater temperature is close to local surface temperature, the groundwater belongs to the shallow active water cycle. TDS in the groundwater is from mineral substances in aquifer rocks [15]. Groundwater in the shallow area generally has less than 1.000 mg/L TDS concentration [16]. Electric conductivity in groundwater represents the total amount of salts dissolved in the water [14]. It means that with the larger conductance, the water is more mineralized [15].

Measurement of groundwater physical-chemical properties is directly done on the field using Hannameter. The temperature was measured in Celsius (°C), TDS in mg/L, and electric conductivity in µS/cm. The measurement of groundwater physical-chemical properties with Hannameter is as simple as dipping the electrode in the 50 ml groundwater sample. Then the result will show on the screen of Hannameter. Measurement for each parameter needs at least 20-50 seconds. After finishing the measurement, the electrode must be washed with aquadest, so no residual sample is attached.
2.4 Analysis of groundwater flow pattern and direction
[14] Groundwater flow patterns consist of equipotential lines. As seen in Figure 4, the direction of groundwater flow will be obtained through the equipotential lines. Groundwater will flow from high equipotential to low equipotential. Mapping of the equipotential line is using GIS. Water table masl from 45 dug wells plotted according to the coordinates to create a raster of the water table. Then, to create the equipotential lines, convert the raster map to contour shape using a contour tool. The contour represents the equipotential line of groundwater flow. The direction of groundwater flow then can be determined from the groundwater equipotential map.

![Figure 4. Creating the pattern and direction of groundwater flow][14].

2.5 Analysis of groundwater physical-chemical properties distribution
Groundwater physical-chemical properties data from 45 dug wells were processed using GIS to map groundwater physical-chemical properties. One map for each parameter. So, there will be a map of pH value distribution, a map of groundwater temperature distribution, a map of TDS distribution, and a map of electric conductivity distribution.

2.6 Analysis of the relationship between the pattern and direction of groundwater flow with the physical-chemical properties of groundwater
The method to analyze the relationship between the pattern and direction of groundwater flow and groundwater's physical-chemical properties is by overlaying the maps. Map of groundwater flow pattern overlaid on each map of the distribution of physical-chemical properties of groundwater. Then, the relationship between the groundwater flow and the physical-chemical properties value of groundwater can be seen through the overlay map.

3. Results and Discussions
Results of water table masl and physical-chemical properties measurement are shown in table 1. Water table masl varies between 21 masl to 94.6 masl. The water table measurement result indicates that the topography of the Randublatung basin affects the water table level. On the west side of the basin, the elevation is around +100 m, and the water table is about 80 masl to 94.6 masl. While on the east side of the basin, the elevation is around +50 m, and the water table is around 30 masl to 21 masl. The pattern and direction of groundwater flow are shown in Figure 5. The direction of groundwater flow in the Randublatung basin is heading to Bengawan Solo River and then following the flow of Bengawan Solo River.
### Table 1. Water table and physical-chemical properties measurement results

| No. | Sample Name | Depth of Water Table (m) | Ground Surface (masl) | Water Table (masl) | pH | Temperature (°C) | TDS (mg/L) | EC (μS/cm) |
|-----|-------------|--------------------------|-----------------------|-------------------|----|-----------------|------------|-----------|
| 1   | SG 01       | -0.8                     | 50                    | 49.2              | 6.8 | 29.6            | 540        | 1090      |
| 2   | SG 04       | -2.0                     | 47                    | 45.0              | 6.6 | 30              | 550        | 1110      |
| 3   | SG 135      | -0.5                     | 62                    | 61.5              | 6.5 | 29.6            | 350        | 730       |
| 4   | SG 158      | -4.5                     | 72                    | 67.5              | 6.4 | 29.6            | 570        | 1150      |
| 5   | SG 18       | -0.3                     | 64                    | 63.7              | 6.7 | 30.4            | 240        | 510       |
| 6   | SG 20       | -0.5                     | 56                    | 55.5              | 6.7 | 30.4            | 360        | 740       |
| 7   | SGB 002     | -6.5                     | 48                    | 41.5              | 7.0 | 28.8            | 490        | 1000      |
| 8   | SGB 003     | -7.2                     | 48                    | 40.8              | 7.0 | 29.8            | 610        | 1240      |
| 9   | SGB 006     | -4.3                     | 52                    | 47.7              | 7.1 | 28.9            | 710        | 1430      |
| 10  | SGB 010     | -9.3                     | 37                    | 27.7              | 7.2 | 28.4            | 400        | 820       |
| 11  | SGB 012     | -9.0                     | 45                    | 36.0              | 7.0 | 33.5            | 450        | 890       |
| 12  | SGB 014     | -0.5                     | 49                    | 48.5              | 7.2 | 28.6            | 130        | 280       |
| 13  | SGB 016     | -15.3                    | 36                    | 21.0              | 6.8 | 29.5            | 410        | 850       |
| 14  | SGB 063     | -1.3                     | 63                    | 61.7              | 6.7 | 28.1            | 310        | 640       |
| 15  | SGB 53      | -1.6                     | 56                    | 54.4              | 6.7 | 30.3            | 700        | 1410      |
| 16  | SGB 70      | 0.0                      | 65                    | 65.0              | 6.6 | 28.2            | 50         | 120       |
| 17  | SGB 78      | -0.4                     | 63                    | 62.6              | 6.4 | 28.9            | 280        | 580       |
| 18  | SGC 004     | -1.1                     | 50                    | 48.9              | 6.9 | 28.9            | 600        | 1220      |
| 19  | SGC 008     | -2.6                     | 40                    | 37.4              | 6.8 | 29.5            | 500        | 1000      |
| 20  | SGC 21      | -0.3                     | 45                    | 44.7              | 7.1 | 27.7            | 540        | 1090      |
| 21  | SGC 22      | -0.1                     | 47                    | 46.9              | 7.3 | 28.6            | 520        | 1070      |
| 22  | SGC 23      | -0.1                     | 50                    | 49.9              | 7.4 | 27.9            | 480        | 1000      |
| 23  | SGC 24      | -0.7                     | 48                    | 47.3              | 7.6 | 28.6            | 400        | 830       |
| 24  | SGC 25      | -0.6                     | 52                    | 51.4              | 7.5 | 27.6            | 560        | 1140      |
| 25  | SGC 28      | -1.2                     | 61                    | 59.8              | 7.1 | 29.4            | 440        | 890       |
| 26  | SGG 02      | -0.3                     | 84                    | 83.7              | 6.5 | 28.3            | 380        | 780       |
| 27  | SGG 03      | -1.0                     | 85                    | 84.0              | 6.6 | 28.1            | 320        | 650       |
| 28  | SGG 04      | -2.4                     | 97                    | 94.6              | 6.1 | 28.8            | 570        | 1160      |
| 29  | SGG 05      | 0.0                      | 86                    | 86.0              | 7.1 | 28.9            | 310        | 640       |
| 30  | SGG 06      | 0.0                      | 90                    | 90.0              | 6.6 | 29.3            | 390        | 810       |
| 31  | SGG 07      | -0.6                     | 83                    | 82.4              | 7.2 | 28.5            | 250        | 510       |
| 32  | SGG 09      | -1.1                     | 91                    | 89.9              | 6.8 | 29.2            | 430        | 870       |
| 33  | SGG 12      | -0.8                     | 75                    | 74.2              | 6.6 | 29.0            | 360        | 720       |
| 34  | SGG 13      | -0.7                     | 75                    | 74.3              | 6.9 | 28.1            | 490        | 990       |
| 35  | SGG 14      | 0.0                      | 76                    | 76.0              | 7.0 | 28.8            | 100        | 230       |
| 36  | SGG 15      | 0.0                      | 72                    | 72.0              | 7.0 | 28.3            | 330        | 670       |
| 37  | SGG 16      | 0.0                      | 68                    | 68.0              | 6.3 | 28.3            | 340        | 690       |
| 38  | SGG 17      | -0.5                     | 60                    | 59.5              | 6.2 | 28.6            | 410        | 840       |
| 39  | SGG 01      | -1.7                     | 89                    | 87.3              | 6.3 | 28.0            | 410        | 840       |
| 40  | SGK 001     | -0.6                     | 50                    | 49.4              | 6.3 | 27.5            | 430        | 870       |
| 41  | SGK 004     | -0.5                     | 40                    | 39.5              | 6.2 | 28.1            | 300        | 610       |
| 42  | SGK 006     | -3.9                     | 47                    | 43.1              | 6.8 | 29.1            | 370        | 760       |
| 43  | SGK 009     | -6.0                     | 35                    | 29.0              | 6.1 | 27.3            | 200        | 770       |
| 44  | SGK 011     | -2.2                     | 39                    | 36.8              | 6.7 | 28.2            | 390        | 790       |
| 45  | SGK 013     | -9.4                     | 43                    | 33.6              | 7.3 | 28.3            | 440        | 890       |
Figure 5. Groundwater pattern and flow direction in Randublatung basin

Figure 6. Distribution of (a) pH value, (b) groundwater temperature (c) TDS value (d) groundwater electric conductivity in Randublatung Basin
The map of physical-chemical distribution is shown in Figure 6. The pH value of groundwater in the Randublatung basin varies between 6.1 and 7.6. Figure 6(a) shows that the highest pH value is located in the middle of the Randublatung basin. The groundwater temperature measurement result is shown in Figure 6(b) explains that the groundwater temperature in the Randublatung basin is between 27.3 °C and 33.5 °C. The highest temperature is located on the east side of the Randublatung basin, with the sampling condition relatively at the same time, namely at noon.

Figure 6(c) shows that the concentration of TDS in the groundwater of the Randublatung basin varies between 50 mg/L and 710 mg/L. The lowest TDS concentration is located on the northwest side of the basin. In comparison, the highest is on the northeast side of the basin. While in Figure 6(d) shows that the electric conductivity rate in the groundwater of the Randublatung basin is between 120 µS/cm to 1430 µS/cm. The distribution map of groundwater electric conductivity that quite similar to the distribution of TDS. Groundwater with the lowest electric conductivity value is located on the northwest side of the basin, and the highest is on the northeast side of the basin.

Our data show no clear indication that the physical-chemical properties of the groundwater follow the flow direction, as shown in Figure 7. Figure 7(a) shows the map overlay between groundwater flow and distribution of pH value. As already mentioned, the groundwater flow is heading to Bengawan Solo River. However, on the west side of the Bengawan Solo River, groundwater has a high pH value and groundwater with a low pH value. It can be said that there is no significant correlation between groundwater flow and groundwater pH value.

The relationship between groundwater flow and groundwater temperature in the Randublatung basin is shown in Figure 7(b). The temperature value is increasing on the east side of the basin. However, on
the middle side of the basin, the temperature is varied. From this condition can be said that there is no significant correlation between groundwater flow and groundwater temperature. The correlation between groundwater flow and groundwater TDS concentration in the Randublatung basin is shown in Figure 7(c). Map overlay shows that groundwater flow direction affects the concentration of TDS in groundwater. The highest concentration of TDS is located on the northeast side of the basin, where groundwater flows the furthest. The groundwater flow map overlay on electric conductivity is shown in Figure 7(d). Similar to the correlation between groundwater flow and TDS value, the direction of groundwater flow also affects the groundwater electric conductivity value. The TDS and electric conductivity value are affected by the mineral substances in aquifer rocks [15]. The farther the groundwater flows, the more it comes into contact with the aquifer rocks and gains more minerals from the rocks, then the TDS and electric conductivity value will increase.

This condition is the same as the research done in Sistan-Baluchestan, Iran [11], Central Mexico [17], and Kosovo [18]. [11] The TDS and groundwater electric conductivity increase as the groundwater flow to the north as the river flows, [17] Groundwater in the plains area has a higher TDS and groundwater electric conductivity value than groundwater in the valley. While the groundwater pH between plains area and valley area has the same average value. In Kosovo, the groundwater flow did not affect the temperature and pH value, but the electric conductivity of groundwater increases as the flow of groundwater to the eastern side of the basin [18].

4. Conclusion
The conclusions of this research are:

- Based on the equipotential map, groundwater in Randublatung Basin flows to Bengawan Solo River and follows the river's flow. The groundwater flow is affected by the topography of the basin that the slope is heading to Bengawan Solo River;
- The groundwater in Randublatung Basin has physical-chemical properties: pH value between 6.1 and 7.6 with 6.8 of average, groundwater temperature between 27.3 °C and 33.5 °C with 28.9 °C average, TDS concentration is 409 mg/L of average, between 50 mg/L and 710 mg/L, and groundwater electric conductivity rate between 120 µS/cm and 1430 µS/cm with the average is 843 µS/cm;
- This research is not using statistical correlation, but in general, no visible correlation between pH and groundwater temperature with groundwater flow. While the TDS value and groundwater electric conductivity increase as the groundwater flow, affected by the mineral of aquifer rocks (alluvial deposits).

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