The Origin of Groundwater on The East Slope of Sumbing Vulcano Using Isotopic Method

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Abstract. The eastern slope of Sumbing Vulcano, Central Java, Indonesia has many springs that causes most people use springs as a source of raw water. This area is part of the Magelang Temanggung Groundwater Basin which abundant groundwater potential. However water demand will continue to increase along with population growth. Therefore, conservative efforts to protect the recharge area are important. This study aims to determine the characteristics of groundwater recharge area on the eastern slope of Sumbing Vulcano using the isotope method. The research method was carried out by taking rainfall samples at 6 different elevations to obtain the meteoric water line (MWL) and the groundwater samples were taken from 11 stations consist of 10 springs and one deep well. The result shown that the recharge area was coming from local recharge with elevation around 273 masl to 1.208 masl.

Keywords: groundwater, isotopes, recharge area

1. Introduction

Most of Java's water needs are met by surface water, especially reservoir water. However, one of the areas in Java that does not depend on reservoir water supply is Magelang and Temanggung Regencies. Both districts use groundwater as the main raw water source [1]. This is because in both areas there are many springs, especially on the eastern slopes of Sumbing Vulcano. This conditions is caused by the fact that the study area is included into quarter volcanic zone [2] that produces andesite to basalt rock composition, either in the form of fine to coarse rock (pyroclastic) or solid or decomposed rock in the form of flows or lava domes. The deposition of these materials forms an aquifer with high porosity and permeability [3][4].

From the hydrogeological conditions, the eastern slope of Sumbing Vulcano is dominated by a medium productivity aquifer with wide spread distribution. In this aquifer, the canal is very diverse, the free ground water table is generally deep, and the well discharge is generally less than 5 l/second [5][6][7].

The geological condition of the study area is located on two sheets of geological maps which are Magelang and Semarang Sheet [8][9]. The formations that make up the aquifer on the eastern slope of Sumbing Vulcano (Figure 1) consist of Old Sumbing Vulcano Deposits (Qsma), Lava and Porphry Andesite (Qp11), Condong Volcanic Rocks (Qco), Gianti Volcanic Rocks, (Qgi), Kekep Volcanic Rocks (Qke), Telomoyo Vulcanic Rock (QTe), Light Sumbing Vulcanic Deposit (Qsm), and Lava Sumbing (Qls2). However, the geological conditions of study area is dominated Light Sumbing Vulcanic Deposit (Qsm). In addition, on the geological map, faults are found in a northwest-southeast direction and a north-south direction. The presence of faults causes the rock layers that act as aquifers to discontinue and affect the flow of groundwater. Therefore, the east slope of Sumbing Vulcano has many springs [10][11].
Based on administrative area, the east slope of Sumbing Vulcano is located in Magelang and Temanggung Regancy, Central Java, Indonesia. Those area belong to the Magelang-Temanggung Groundwater Basin which has 886 million m3/year of groundwater potential. This number divine into 2 aquifers which are 872 million m3/year (98.4%) in free aquifer and 14 million m3/year (1.6%) in confined aquifer [12]. Meanwhile, household, urban and industrial water needs (RKI) in 2020 in this area is 117.8 million m3/year and estimated will be 120.6 million m3/year in 2030 [1].

This research is done as one of the conservative efforts in protecting the recharge area to ensure the sustainability of groundwater in the study area. Several methods for determining groundwater recharge areas are buckling method, river flow patterns, springs emergence, groundwater level, and groundwater chemistry and isotopes [13][14]. However, the isotope method is generally used to determine the recharge area [10]. Therefore, this study aims to determine the recharge area of the east slope of Sumbing Vulcano, Central Java, Indonesia using the isotope method. This knowledge will be useful in protecting the sustainable use of groundwater.

Isotopes in water consist of light hydrogen (\(^{1}H\)), heavy hydrogen (\(^{2}H\) or D), light oxygen (\(^{16}O\)), rare oxygen (\(^{17}O\)), heavy oxygen (\(^{18}O\)). The isotopes that are generally used in hydrological system research include stable isotopes, consisting of deuterium (\(^{2}H\) or D), oxygen-17 (\(^{17}O\)), oxygen-18 (\(^{18}O\)), carbon-13 (\(^{13}C\)), and unstable or radioactive isotopes, namely tritium (\(^{3}H\)) and carbon-14 (\(^{14}C\)) [13].

Isotope analysis in determining the recharge area is carried out by formulating the meteoric water line (MWL) equation from the distribution isotopes value of \(^{2}H\) and \(^{18}O\) or called \(^{\text{TM}}D\) and \(^{\text{TM}}^{18}O\). A meteoric water line (MWL) is a reference line to understand and trace the origin and movement of groundwater in an area. MWL is obtained from the isotope relationship \(^{\text{TM}}D\) on the y-axis and \(^{\text{TM}}^{18}O\) on the x-axis contained in rainfall. The MWL and general equation for MWL is shown in Figure 2 and Equation 1 [13].

\[^{\text{TM}}D = a^{\text{TM}}^{18}O + b\] (Equation 1)
There are two kinds of MWL called global meteoric water line (GMWL) and Local Meteoric Water Line (LMWL). GMWL is the general meteoric relationship between δD and δ¹⁸O were found to be linear for natural water and has been defined with the following equation for freshwater, which is shown in Equation 2 [14]. To determine the elevation of the recharge area, a composition diagram is used by analysis the comparison of the δ¹⁸O and δD rainfall isotope relationships as shown in Figure 3 [10].

\[ \delta^2H = 8 \times \delta^{18}O + 10 \% \quad \text{(Equation 2)} \]

The LMWL is MWL representing the actual condition in a specific area influenced by several factors consisting of temperature, seasonal differences, altitude, rainfall, and continental conditions. The higher temperature and rainfall make water enrich δ¹⁸O. Meanwhile, the higher altitude and distance of the area from sea or ocean waters makes water deplete of δ¹⁸O. This is because the heavy isotopic composition will decrease. The δ¹⁸O will decrease 0.15‰ until 0.50‰ every 100 m elevation increase, while of δD will decrease 1‰ until 4‰. In addition, this is due to evaporation during the movement of a collection of water droplets in the atmosphere [13][14].

One of the main causes of changes in isotopic composition is evaporation. This occurs especially in arid and semiarid areas where the evaporation is also closely related to temperature, geological conditions, and relative humidity that determine the evaporation slope line [15][16][17]. Therefore, the isotopic composition determines the recharge area and identifies the rate of precipitation and evaporation. The way is by analyzing the deviation of the groundwater isotopic composition to LMWL. If the slopes of the groundwater samples are higher than the slope of the LMWL, it indicates a relatively low rate of evaporation and reflects high altitude recharge. The lower slope indicates a high rate of evaporation of surface water prior to infiltration [17].

There is a degree of evaporation or deuterium excess value (d-excess) that could be a second-order parameter and reflects non-equilibrium fractionation during initial evaporation from the ocean, re-evaporation at the land surface, or re-evaporation and mixing along the water mass trajectory. D-excess is defined in Equation 3 [17][18]. Positive d-excess values indicate low evaporation and show that it forms from meteoric origin while negative d-excess indicate high evaporation. The d-excess value ranged from 7‰ to 14‰ with dominant value is higher than 10‰ indicates that seawater is significant contributes of recycle continental water vapor to rainfall [19]. The narrow range of groundwater isotopes with LMWL indicates that water is from recent recharge and rapid infiltration through fractured rocks [20][21].

\[ \text{d-excess} = \delta D - (8 \times \delta^{18}O) \quad \text{(Equation 3)} \]
2. Methods of Research

The research was conducted by taking samples of rainfall and groundwater scattered in the study area. The rainfall samples were taken at 6 stations at various elevations. Meanwhile, groundwater samples were taken from 10 springs and one deep well. The sampling location is shown in Figure 4 while the details of the location and elevation of each sample are shown in Table 1.

Based on Figure 4 and Table 1, it can be seen that the sampling of rainfall has a tendency of higher elevation to the north and getting further from the seawater. This was done in line with the statement regarding the higher the altitude and the further the location of the rain, the isotopic composition of $\delta^{18}$O and $\delta D$ is getting more depleted.

Sampling was carried out in the rainy season with a number of two bottles with 150 ml each. The samples were then tested for $\delta^{18}$O and $\delta D$ isotopes using a liquid water isotope analyzer LGR (Los Gatos Research) DLT-100 by the Central Laboratory of Radioactive and Isotope Applications in BATAN, Jakarta, Indonesia.

The next analysis is carried out by formulating the Meteoric Water line which consists of the Local Meteoric Water Line (LMWL) and the global Meteoric Water Line (GMWL). By knowing the comparison of LMWL, GMWL, and the distribution of groundwater isotopes, it can be concluded the characteristics of the recharge area related to evaporation and infiltration. Furthermore, through the composition diagram of isotopes $\delta^{18}$O and $\delta D$ compared to altitude of rainfall, the elevation of the recharge area can be determined. Figure 5 shows LMWL and GMWL while Figure 6 shows the slope of groundwater isotopes $\delta^{18}$O and $\delta D$.

| No | Sample Codes | Kind | Location | Coordinate X | Coordinate Y | Altitude (masl) |
|----|---------------|------|----------|--------------|--------------|----------------|
| 1  | AH 347        | Rainfall | Magelang | 110,1946     | 7,49498     | 347            |
| 2  | AH 483        | Rainfall | Magelang | 110,1839     | 7,46522     | 483            |
| 3  | AH 680        | Rainfall | Magelang | 110,1500     | 7,44988     | 680            |
| 4  | AH 860        | Rainfall | Magelang | 110,1578     | 7,39625     | 860            |
| 5  | AH 1083       | Rainfall | Temanggung | 110,1245   | 7,34160     | 1.083          |
| 6  | AH 1239       | Rainfall | Temanggung | 110,1160   | 7,35030     | 1.239          |
| 7  | STA 5         | Spring  | Temanggung | 110,0806   | 7,30672     | 1.018          |
| 8  | STA 9         | Spring  | Temanggung | 110,1185   | 7,35788     | 1.208          |
| 9  | STA 10        | Spring  | Temanggung | 110,1264   | 7,36596     | 1.112          |
| 10 | STA 12        | Spring  | Temanggung | 110,1711   | 7,37820     | 657            |
| 11 | STA 13        | Spring  | Temanggung | 110,1421   | 7,32852     | 798            |
| 12 | STA 24        | Deep Well | Temanggung | 110,1845   | 7,33563     | 543            |
| 13 | STA 38        | Spring  | Magelang  | 110,1431    | 7,52845     | 386            |
| 14 | STA 43        | Spring  | Magelang  | 110,1413    | 7,45683     | 693            |
| 15 | STA 50        | Spring  | Magelang  | 110,1065    | 7,50252     | 568            |
3. **Result and Discussion**

Based on the laboratory test, the isotopic compositions of d18O and dD are shown in Table 2. Based on the results of the isotope testing, an analysis of the LMWL and GMWL and the groundwater distribution isotopes was carried out as shown in Figure 5.

According to the Figure 5, the LMWL equation at the study area (Equation 4) is obtained. If the equation of LMWL is compared with GMWL, it can be concluded that both equation of the LMWL at the research site and GMWR (Equation 2) are identical. It shows that the origin and movement of groundwater flow in the study area has similar characteristics to the global standard which is define as natural water or fresh water.

Observing the distribution of δ18O and δD isotopes from groundwater to LMWL will conclude that the distribution plot of groundwater isotope is around LMWL. Therefore, it indicates that groundwater comes from meteoric origin. The narrow range of groundwater isotopes with LMWL indicates that water is from recent recharge and rapid infiltration through fractured rocks.

| Sta No. | Name  | Location | Longitude  | Latitude  | δ18O | δD  |
|---------|-------|----------|------------|-----------|------|-----|
| 16      | STA 52 | Spring   | Magelang   | 110,0919  | 7.44259 | 1.126 |
| 17      | STA 56 | Spring   | Magelang   | 110,1655  | 7.42405 | 827  |

**Figure 4** Location of rainfall and groundwater samples in topography map of study area
Figure 5 The meteoric water line and groundwater isotopes ($\delta^{18}O$ and $\delta D$)

\[ TMD = 7.999 \ TMO\delta^{18}O + 10.111 \ldots \quad (Equation 4) \]

Figure 6 The slope of groundwater isotopes ($\delta^{18}O$ and $\delta D$)

\[ TMD = 7.21 \ TMO\delta^{18}O + 5.4887 \ldots \quad (Equation 5) \]

From the Figure 6 and Equation 5, it can be seen that the slope of groundwater isotopes $d_{18}O$ and $\delta D$ is 7.2. Meanwhile based on Equation 4, the LMWL slope is 7.9. It can be concluded that the lower slope of groundwater isotopes compared to LMWL indicates a high rate of evaporation of surface water before infiltration in the study area.

Besides using the slope of groundwater isotope, evaporation characteristics can be analysis using $d$-excess. The Table 2 shows that the value of $d$-excess is positive which is indicative of low evaporation and shows that it forms from meteoric origin. Furthermore, the $d$-excess value ranged from 9‰ to 12‰ with dominant value is higher than 10‰ indicates that seawater is a significant contributing of recycle continental water vapor to rainfall.

Table 2 Result of laboratory test and analysis

| No | Sample Codes | Altitude (masl) | Isotopes | Elevation Recharge Area (y) (masl) | $d$-excess (‰) |
|----|--------------|----------------|----------|-----------------------------------|----------------|
| 1  | AH 347       | 347            | -6.3     | -41.4                             | 318.4          | 357.60 | 9.00 |
| 2  | AH 483       | 483            | -6.93    | -43.4                             | 462.0          | 413.63 | 12.04 |
| 3  | AH 680       | 680            | -8.2     | -56.2                             | 751.6          | 772.21 | 9.40 |
| 4  | AH 860       | 860            | -9.04    | -63.0                             | 943.1          | 962.70 | 9.32 |
| 5  | AH 1083      | 1.083          | -9.35    | -64.2                             | 1.013,8        | 996.32 | 10.60 |
| 6  | AH 1239      | 1.239          | -10.18   | -71.10                            | 1.203,0        | 1.189,62 | 10.34 |
| 7  | STA 5        | 1.018          | -6.91    | -45.8                             | 457.5          | 480.86 | 9.48 |
| 8  | STA 9        | 1.208          | -7.10    | -45.30                            | 500.8          | 466.85 | 11.50 |
| 9  | STA 10       | 1.112          | -7.03    | -44.40                            | 484.8          | 441.64 | 11.84 |
| 10 | STA 12       | 657            | -6.88    | -43.90                            | 450.6          | 427.63 | 11.14 |
| 11 | STA 13       | 798            | -6.83    | -44.00                            | 439.2          | 430.44 | 10.64 |
| 12 | STA 24       | 543            | -7.11    | -45.80                            | 503.1          | 480.86 | 11.08 |
| 13 | STA 38       | 386            | -6.19    | -40.00                            | 293.3          | 318.38 | 9.52 |
| 14 | STA 43       | 693            | -6.60    | -41.70                            | 386.8          | 366.00 | 11.10 |
| 15 | STA 50       | 568            | -6.13    | -38.40                            | 279.6          | 273.56 | 10.64 |
After knowing that the groundwater in the study location comes from meteoric origin with high evaporation before infiltration which is the infiltration is rapidly through fractured rocks, then an analysis is carried out to determine the elevation of the recharge area. Analysis of the recharge area elevation is done using the isotope composition diagram consisting of $\delta^{18}O$ and $\delta^D$ which is compared to altitude as shown in Figure 7 and Figure 8.

Based on the composition diagram, it can be obtained two equations which show in Equation 6 and Equation 7. Furthermore, the results of the testing of groundwater isotopes $\delta^{18}O$ and $\delta^D$ in Table 2 are substituted into the both equations. The result is shown in the Table 2. However, from the Table 2 it can be seen that the recharge area has a lower elevation than the groundwater sampling location. This shows that the recharge area of groundwater comes from the area around the emergence of groundwater (local recharge) and classified as shallow groundwater. So it can be estimated that the recharge area is on elevation between 273 masl to 1,208 masl since the highest spring elevation or STA 9 was found in this location.

$$y = -228^{\text{m}}\delta^O - 1.118 \quad \ldots \ldots \ldots (\text{Equation 6})$$

$$y = -28.014^{\text{m}}\delta D - 802.18 \quad \ldots \ldots \ldots (\text{Equation 7})$$

4. Conclusion

Through this research, it can be concluded that the origin of groundwater on the eastern slope of Sumbing Vulcano is from meteoric origin with high evaporation before infiltration, which is the infiltration is rapidly through the fractured rocks. The recharge area of groundwater comes from local recharge between 273 masl to 1,208 masl and classified as shallow groundwater. In addition, from the results of the LMWL analysis, it can be seen that the research location has a LMWL’s equation which is very similar to the GMWL’s equation. This shows that the study area has similar characteristics to the global standard which is define as natural water or fresh water.
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