Stable isotopes changes in groundwater: a case study in Mudal and Clapar springs, West Progo

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Abstract. Hydroisotope studies were carried out on Mudal and Clapar springs located in the central part of the West Progo Dome. The research was conducted by taking samples of groundwater in each spring for three periods, representing the rainy (2016), dry (2017), and rainy (2018) seasons. Data on stable isotope content of $^{18}$O and D were analyzed to see the hydroisotope characteristics of groundwater and their relationship to climate change. The results show that the stable isotope content of groundwater in both springs was relatively stable, with insignificant changes over time and season. Mudal springs tend to show light isotopes, indicating deep aquifer or high elevation recharge, less affected by the season. Clapar spring shows heavy isotopes, which may be sourced from a shallow aquifer with mixing/evaporation processes and are more influenced by the season. Meanwhile, the range value of $\delta$D in the two springs shows slightly - totally changes, indicating that the D content also changes due to seasons, although it is small. The $\delta$D enrichment shows the medium-large change in both spring springs, but uncertainty in Mudal. However, the D-excess value shows that the dry and rainy season conditions, which may be related to temperature or precipitation, are not much different.

1. Introduction
The study of groundwater has been developed because this natural resource is becoming increasingly important over time, in line with the needs of living things for groundwater. Various groundwater studies have been carried out, both physically and chemically [1-5]. Hydrochemical studies were also developed using various methods, complemented by studies of groundwater isotopes. Isotope analysis is helpful to aid in the interpretation of groundwater flows as well as aid in its genetic interpretation. The results of hydrochemical groundwater analysis can be verified by isotope analysis to produce a better interpretation of the groundwater flow system. In addition, isotope studies have also been developed using stable isotopes $^{18}$O and $^2$H (deuterium / D). One of the hydroisotope studies that can be done is related to the climate aspect in an area.

Stable isotope analysis helps know the origin of groundwater and the interpretation of catchment areas. In addition, stable isotope data can also analyze hydrochemical processes due to seasonal changes [6]. This paper intends to discuss the characteristics of the stable isotopes $^{18}$O and D, particularly concerning seasonal changes in the West Progo Hills area. The case study, in this research, was carried out on the Mudal and Clapar springs located in the central part of the West Progo Dome physiography [7].

Mudal spring is at an elevation of 664 meters above sea level (masl), emerging from the limestone aquifer of the Jonggrangan Formation in Banyunganti Hamlet, Jatimulyo Village, Girimulyo Subdistrict. Meanwhile, the Clapar spring is at an elevation of 437 masl, emerging from the andesite
breccia aquifer of the Old Andesite Formation in Clapar II Hamlet, Hargowilis Village, Kokap Subdistrict, West Progo Regency (Figure 1).

The study area is included in the physiography of the Dome and Hills Zone in the Central Depression [7]. The center of this dome physiography forms the morphology of the Jonggrangan plateau. The Jonggrangan Formation is quite extensive in this area. Around the Jonggrangan highlands, volcanic rocks from the Old Andesite Formation are exposed (Figure 1) [8].

The regional stratigraphy of the West Progo Mountains from the oldest to the young is composed of the Nanggulan, Old Andesite, Jonggrangan, Sentolo Formations, and Alluvial Deposits [7-9]. The Jonggrangan Formation comprises conglomerates, tuff marl, and limestone sandstones with lignite inserts, layered limestone, and coral limestone. Meanwhile, the Old Andesite Formation comprises andesite breccias, tuffs, lapilli, agglomerates, and intercalation of andesite [8]. Mudal spring appears in the Jonggrangan Formation rocks, while Clapar spring appears in the Old Andesite Formation (Figure 2).
Although West Progo Hills is classified as a non-groundwater basin [10], many springs can be found even though they generally have small discharges. However, several springs with moderate to large discharge can also be found on these hills. Large discharge can be found in the limestone aquifers of the Jonggrangan Formation. The presence of springs in the West Progo Hills zone is highly controlled by the local topography [11] and lineament factors [12]. Geological lineaments influence the occurrence of springs, especially significantly controlled by the density and distance of lineaments to the location of the springs.

2. Method
The research begins with a hydrogeological survey to determine the geological conditions and springs in the study area. Several springs with small to large discharge are found in the central part of the West Progo area. This area is dominated by limestones of the Jonggrangan Formation and andesite breccias of the Old Andesite Formation. Springs with a large discharge were selected as the sample of this study. Mudal springs have large discharge and represent the aquifer of the Jonggrangan Formation, while the Clapar springs are medium/large enough and represent the Old Andesite Formation. This research focuses on isotope studies, but some groundwater hydrochemical data is also taken together with isotope sampling in the field.

Groundwater samples from both springs were taken in three periods: period I in the rainy season in December 2016, period II in the dry season (August 2017), and period III in the rainy season (March 2018). Precipitation of the research area at the time of sampling can be seen in Table 1. The difference in sampling time from each period to the next is around eight months. In each sample, 30 ml of groundwater was put into an airtight bottle (polyethylene) by inserting the bottle into a water source to avoid evaporation.

| Spring | Dec 2016 | Aug 2017 | Mar 2018 |
|--------|----------|----------|----------|
| Mudal  | 216      | 2.5      | 218      |
| Clapar | 311      | 13       | 152      |

Isotope testing was carried out at the Hydrology Laboratory, Center for Isotope and Radiation Application (PAIR) - National Nuclear Energy Agency (BATAN), located in Pasar Jumat, South Jakarta. Isotope content in groundwater samples was determined using a Liquid Water Stable Isotope Analyzer (LWIA) type DLT-100 made by LGR (Los Gatos Research) USA. The isotope content analyzed is oxygen-18 (18O) and hydrogen (2H), known as deuterium (D) isotope. A mass spectrometer measured isotope ratios, and the results were referenced against the SMOW standard. The internal standard was calibrated using V-SMOW with an analysis accuracy of ± 0.1 for δ18O and ± 1‰ for δD [3]. Furthermore, the stable isotope test results were analyzed to determine the changes and interpret the influence of the seasons/climate in the study area.

Isotope data analysis was carried out by looking at the absolute value trend and the relative value of Mudal and Clapar isotope content in three periods. In addition, the δ18O and δD relationships in groundwater springs compared with meteoric water lines were also analyzed to assist in the genetic evaluation of groundwater in the springs. Analysis of changes in isotope content related to seasonal effects can be done by looking at the δD enrichment and D-excess (d) of the groundwater.

3. Stable isotope review
Isotopes are elements that have the same atomic number but different mass numbers [16]. In nature, isotopes in water can be found as stable or radioactive isotopes. The content of radioactive isotopes in water can determine age, while stable isotopes help determine water genetics [17].

Isotopes contained in water, namely hydrogen atoms (1H, 2H, 3H) and oxygen atoms (16O, 17O, 18O), often be used in hydrogeological studies [18,19]. The abundance of 1H isotope is about 99.985%, 2H is
about 0.015%, and $^3$H is < 0.001%, while the $^{16}$O isotope is about 99.63%, $^{17}$O is about 0.0375%, and $^{18}$O is around 0.195% [17]. Isotope abundance is measured by the ratio of the deviation from the standard [16]. The stable isotopes $^{18}$O and $^2$H are present in water in compounds $^{1}$H$^{2}$H$^{16}$O and $^4$H$^2$H$^{16}$O$^2$ [17,20]. Since the abundance of H$_{2}^{18}$O and HD$^{16}$O molecules compared to the abundance of H$_2^{16}$O is very small, the measured abundance is usually the relative abundance of an international standard water / SMOW (Standard Mean Ocean Water) [6].

The $^{18}$O and D isotopes are often used in the study of chemical processes. This isotope is a stable, non-radioactive isotope and is often used to indicate groundwater sources [6]. The $^{18}$O and $^2$H isotopes are natural tracers because they are stable [21-23]. That is, they are not affected by the water-rock interaction process at low temperatures [24]. Therefore, isotopes are often used in genetic studies to determine groundwater infiltration zones [5,25-28] and studies of mixing groundwater from different sources [29]. The geological structure control in deep groundwater flow systems can also be determined by groundwater isotope analysis [5].

The $^{18}$O and D isotopes are very sensitive to physical processes such as evaporation and condensation. Therefore, the content of these stable isotopes can be used to see the climate effect on springs. The isotopic fractionation process in precipitation is a temperature-dependent process [6]. Thus, if there is a change in seasonal temperature in a place, it will be seen that there is a variation in the stable isotope composition of the precipitation where a light value occurs in a cold month. For the same reason, precipitation will also have a lighter isotope content in the arctic/high latitudes, further away from the sea, and higher elevation places. For every 100 m elevation increase, $^{18}$O in the rainwater will decrease by 0.15 - 0.5 ‰, and $^2$H will be depleted by 1 - 4‰ [30].

Stable isotope content in rainwater shows a linear relationship in the form of a global meteoric water line. The relationship between $\delta^{18}$O and $\delta$D of the precipitation water follows the equation of the meteoric water line. From the results of the global investigation [31], the equation for the meteoric water line (GMWL) was known as $\delta D = 8\delta^{18}O + 10‰$. Rainwater tends to contain the stable isotopes $\delta^{18}O$ and $\delta^2H$, which are depleted at higher latitudes. This phenomenon also occurs when the two stable isotopes move deep inland. For this reason, the plot results of the two isotopes yield slightly different slopes known as the local meteoric water line [32].

Based on the research of the recharge area of the underground river water system in Gunungkidul, Yogyakarta [3], it is known that the local meteoric water line (LMWL) equation for the area is $\delta^2H = 7.978 \delta^{18}O + 8.423 \‰$. This LMWL value is then used for isotope studies in the West Progo area because of its relatively close location and considering that the LMWL value in this area is not yet available.

To see the influence of climate/rainfall, regression line relationships $\delta^{18}$O and $\delta$D groundwater can be plotted together with the global meteoric water line GWML or the local meteoric water line (LMWL). If the groundwater regression line is adjacent to the LMWL, the groundwater is affected by local climate (originating from local precipitation) or topographic effects [1].

4. Result and discussion

4.1. Spring characteristic

Mudal Springs emerge from the Jonggrangan reef limestone aquifer, supported by large porosity permeability. The porosity developed as fracture and channel types. Jonggrangan limestone is dominated by thick to massive layered coral limestones. Around the Muradal springs, these reef limestone outcrops show white to brownish-white color, compact and hard, with some fairly intensive tectonic of joints characteristics. Mudal Springs has a large fluctuation in discharge. The discharges show; moderate magnitude during the dry season but can be very large discharges during the rainy season [11]. When the isotope sampling was carried out, the Mudal spring discharge was measured to be 100 - 236 L/s, but at the end of the dry season (September 2018), it appears that this discharge has decreased drastically to <50 L/s. The spring can be classified as depressions, fractures, or channels type of spring. Mudal spring has a large flow that develops as runoff/rivers. This spring is a perennial
spring, although it has a significant change of discharge over the season. Based on its temperature, Mudal is classified as a normal spring. The physicochemical data show groundwater of Mudal spring has a temperature range of 23.1 – 24°C, pH of 6.7 – 8.3, TDS of 225 – 254 ppm, and EC of 380 – 418 μS /cm.

Meanwhile, Clapar springs have smaller dimensions than Mudal springs. Clapar springs emerge from aquifers in andesite breccias and autoclastic / lava breccias of the Old Andesite Formation, supported by fracture and sheeting joints porosity with moderate intensity controlled by low - medium permeability. Clapar springs have fracture-type springs. The discharge of springs is usually small (stagnant) - medium flow rate, with small discharge fluctuation. These springs can be classified as normal springs based on the temperature of the water. The physicochemical data of these springs show a temperature of 23.7 – 24.5°C, with a pH range of 7 – 8.2, TDS of 75 – 97 ppm, and EC of 157 – 185 μS /cm.

4.2. $^{18}O$ and $^2H$ isotopes contents analysis

Stable isotope content data in Mudal and Clapar spring water can be seen in Table 2 below. Furthermore, the isotope content's absolute value and range value can be analyzed to determine the hydrochemical processes that occur in the groundwater system.

Table 2. Data on stable isotope content of groundwater from the investigated springs.

| Spring | I (Dec 2016) | II (Aug 2017) | III (Mar 2018) |
|--------|-------------|---------------|----------------|
|        | $^{18}O$ (%) | D (%)         | $^{18}O$ (%)   | D (%)         | $^{18}O$ (%) | D (%)         |
| Mudal  | -7.1 ± 0.11 | -41.7 ± 0.4   | -7.39 ± 0.42   | -45.1 ± 3.1   | -6.94 ± 0.39 | -50.2 ± 1.5   |
| Clapar | -6.25 ± 0.07| -40 ± 1.8     | -5.51 ± 0.32   | -34.7 ± 1.0   | -4.77 ± 0.34 | -38.3 ± 3     |

4.2.1. Absolute value of $\delta^{18}O$ and $\delta D$. From period I to III, Mudal springs showed relatively stable O isotope, while D isotope tended to be lighter (Figure 3). Groundwater with light isotope generally flows in deep aquifers or comes from high absorption areas [2], as seen in Mudal springs, which have light D isotope ($-50.2\%$) in period III (Figure 3; Table 3). It means that groundwater that appears in Mudal springs may flow in deep enough aquifers or originate from precipitation of rainwater that infiltrates at a high enough elevation. The infiltration zone may exist locally because the Mudal springs are indeed at a high enough elevation.

Clapar springs have groundwater with $^{18}O$ heavier from period I to III and a relatively stable D isotope. The heavy isotopes in springs indicate a mixing or evaporation process [1, 2], strongly supported by groundwater isotopes of dug wells in the area [33]. The D isotope indicates a shallow
Thus, the groundwater in the Clapar springs comes from shallow aquifers that have undergone a mixing or evaporation process.

Table 3. Changes in the stable isotope content of the springs.

| Variable | Spring       | \( \delta^{18}O \) (‰) | \( \delta D \) (‰) |
|----------|--------------|-------------------------|-------------------|
| Time     | Mudal        | down-up, stable relatively difference = 0.45 ‰ | get lighter difference = 8.5 ‰ |
|          | Clapar       | get heavier difference = 1.48 ‰ | up - down, stable relatively difference = 5.3 ‰ |
| Season (T-effect) | Mudal        | lower when dry no effect | higher when dry |
|          | Clapar       | no effect | |

Compared to Clapar springs, Mudal springs contain lighter \(^{18}O \) and D isotopes in the three periods studied. It shows that the stable isotopes possessed by the two springs are relatively consistent, whereas the Mudal springs tend to have genetics from deeper aquifers (Table 4).

Table 4. Interpretation of light / heavy isotope content.

| Spring | I          | II         | III         | Interpretation                      |
|--------|------------|------------|-------------|-------------------------------------|
|        | \( \delta^{18}O \) (‰) | \( \delta D \) (‰) | \( \delta^{18}O \) (‰) | \( \delta D \) (‰) | | |
| Mudal  | -7.1       | -41.7      | -7.39       | -45.1                               | -6.94                               | -50.2 | - Deep aquifer, or - High elevation recharge |
| Clapar | -6.25      | -40        | -5.51       | -34.7                               | -4.77                               | -38.3 | - Shallow aquifer - Mixing with runoff or other sources/evaporation |

When compared with GMWL and LMWL, it appears that the absolute values of isotopes contained in the Mudal springs at all periods tend to move away from the two meteoric water lines (Figure 4). Clapar springs contain isotopes that tend to be close to the meteoric water line during the rainy (period I) and dry (II) seasons. This considerable deviation in period III for Clapar springs indicates the influence of the water from other sources or runoff.

Figure 4. The relation of \( \delta^{18}O \) and \( \delta D \) in groundwater of springs.
The interpretation of water sources in the Mudal and Clapar springs is also supported by physicochemical data from the groundwater. Mudal springs release water from deep aquifers characterized by cooler temperatures. According to other researchers, a higher temperature may be sourced from mixing groundwater and surface water [2]. The pH value, which tends to be alkaline, indicates a long interaction with carbonate rocks in the relatively deeper aquifer. This condition is also supported by the greater TDS and EC values of water from the Mudal springs than Clapar.

4.2.2 Range value of δ¹⁸O and δD. The stable isotope content studied showed a short range of values and generally did not have overlapping values (Figure 5). With due regard to the δ¹⁸O range value in all periods, it appears that the groundwater from Mudal springs has isotopes δ¹⁸O is light, while the Clapar springs have value δ¹⁸O. The overlapping values in the three periods in Mudal springs indicate that groundwater in these springs is less affected by seasonal changes, while seasonal changes have more effect on Clapar springs.

The widest δD range value occurs in Mudal and Clapar springs at different periods (Figure 5). The δD value, which is relatively stable, light but appears to shift in the Mudal spring, indicates that the groundwater in this spring is less affected by seasonal changes, with relatively deep circulation. As for the springs, Clapar has relatively stable (heavy) δD, which shows significant overlapping in the rainy period, slightly different from the range value in the dry season, indicating that groundwater in these springs is immensely affected by changes in the season. Referring to previous research [2], groundwater with heavy δD as in the Clapar springs can be interpreted as a result of a fairly intensive mixing or evaporation process (Table 5).

Monthly rainfall in the three periods shows that during the rainy season, there is quite a lot of precipitation in both Mudal and Clapar (Table 1). In the dry season (period II), the precipitation is very low. However, the values range δ¹⁸O for Mudal spring did not show any clear changes. The δ¹⁸O isotope content in Mudal springs is relatively stable and less affected by the amount of precipitation. It also indicates that the Mudal springs are supported by relatively deeper aquifers.

![Figure 5](image)

**Figure 5.** The values range δ¹⁸O and δD for Mudal and Clapar springs. The overlapping values indicate the similarity of δD in different seasons.

**Table 5.** Value range interpretation δ¹⁸O and δD.

| Springs | δ¹⁸O       | δD            | Analysis                                           |
|---------|------------|---------------|----------------------------------------------------|
| Mudal   | In short, some overlap | Short and long, shifted | δ¹⁸O and δD are relatively stable/light, less affected by seasonal changes |
| Clapar  | Short - long, shifted, enrichment | Short-a bit long, overlap significantly in the rainy season | δ¹⁸O and δD relatively stable/heavy, affected by season, intensive evaporation/mixing |
Change $\delta D$ of groundwater usually occurs due to isotopic exchange with minerals containing hydrogen, such as gypsum and clay minerals [34,35]. However, data does not support this exchange. The $\delta D$ in these two materials is unknown, so the cause of the $\delta D$ change in groundwater is still difficult to determine. Moreover, this variation in value is usually not large, so this exchange is considered insignificant. Furthermore, membrane filtration is associated with increased $\delta D$. It is difficult to happen in the study area because this process usually requires high pressure, which is equivalent to a sediment depth of 1.6 km [36]. In sedimentary rock formations, less than 1 km deep membrane filtration is less effective [37].

4.3. The effects of season on $\delta^{18}O$ and $\delta D$ changes

The process that occurs related to the seasonal effect can be assessed based on the $\delta^{18}O$ against $\delta D$ of groundwater relationship. In the dry season (period II), the regression line of springs in the study area is very close to the LMWL, indicating that meteoric water isotope content enrichment has not been clearly seen [38]. However, the climatic influence in this dry season can be seen from the presence of de-excess [1]. Further research added that the value of the line gradient is in the range 3-6, indicating an evaporation process [31].

The groundwater line in period III was partly below the LMWL, which indicates that it experienced isotopic enrichment [1,11], for example, due to a fairly intensive evaporation process or mixing with surface water/runoff. The slope of the regression line smaller than the LMWL gradient indicates a variation in evaporation rate. In addition, evaporation may occur in the catchment area along with the infiltration process [2].

4.3.1. The enrichment of $^{18}O$ and D stable isotopes. Changes in stable isotope content associated with changing seasons can cause an $\delta D$ or $\delta^{18}O$ enrichment effect. $O-18$ isotope enrichment during the rainy season relative to the dry season occurs in Mudal springs, while $\delta D$ isotope enrichment occurs in Clapar springs in the dry season compared to the rainy season (Table 6; Figure 3).

Isotopic enrichment $\delta^{18}O$ in the rainy season relative to the dry season in Mudal springs is related to the isotopic fractionation of carbonate rocks due to water-rock interaction. It was also supported by the greater TDS and EC values of groundwater in the Mudal than Clapar springs, both during the rainy and dry seasons. Enrichment of $\delta^{18}O$ can be caused by carbonate minerals [35,37]. Meanwhile, the $\delta D$ enrichment of Clapar springs occurs, indicating that seasonality affects the content of these stable isotopes. The season affects the evaporation process, which can enrich the isotopic content of groundwater.

Table 6 shows the degrees of $\delta D$ enrichment in the springs studied. The degree of $\delta D$ enrichment is calculated in the dry season (period II) relative to the rainy season, both periods I and III. The magnitude of the changes caused by D isotope enrichment can be seen in Figure 6.

| Spring | $\delta D$ dry (Period II) | $\delta D$ rainy | Enrichment Degree | Explanation |
|--------|----------------------------|------------------|-------------------|-------------|
|        | $\delta D$ dry (Period II) | $\delta D$ rainy | Enrichment Degree | Explanation |
|        | Period I | Period III |        |              |             |
| Mudal  | -45.1    | -41.7       | -50.2 | -3.4 - 5.1  | Uncertainty |
| Clapar | -34.7    | -40         | -38.3 | 3.6 - 5.3   | Medium-large |

*) Negative values indicate enrichment during the rainy season

Figure 6 shows that the Mudal spring has a medium-large $\delta D$ enrichment (>5‰) but is not related to seasonal changes. The Clapar springs undergo moderate - large changes due to enrichment during the dry season. The $\delta D$ enrichment in the Clapar springs in the dry season shows a seasonal effect on the D isotope of groundwater. It is confirmed by a shift in $\delta D$ values that can occur due to seasonal changes [2].
A spring that has δD enrichment >5‰ is classified to have a large change, while moderate change is indicated by D enrichment of 3 - 5‰. Meanwhile, a small change is indicated by δD enrichment of 1 - 3‰ [2]. The enrichment δD <1 indicates no enrichment. If the δD range value is considered, some groundwater samples appear to have shifted (Figure 6). The two springs have shifted slightly - totally change.

4.3.2. The “d” value (δD-excess). Changes in stable isotope content can occur due to the influence of seasons due to temperature differences. Usually, the temperature effect is related to the elevation of an area. However, it is difficult to study the effect of elevation in this study, considering that the two springs studied do not have a contrasting elevation difference. The humidity aspect also cannot be studied considering the absence of data. Isotope data in the two investigated springs showed good δ18O, nor δD varies considerably, both in absolute value and in range. The data that is not much different is generally considered to have no seasonal variation (temperature effect) [1]. However, if we examine one by one, there is a "d" variable which is δD-excess which we can calculate (Table 7). The value of “d” in general can be calculated with the following formula [1].

\[ d = \delta D - 8\delta^{18}O \]  

Figure 6. D-enrichment of groundwater in Mudal and Clapar springs.

| Spring  | δD-excess (“d”) (%) |
|---------|---------------------|
|         | I               | II              | III             |
| Mudal   | 15.1            | 14.02           | 5.32            |
| Clapar  | 10              | 9.38            | -0.14           |

The “d” value or δD excess indicates the presence of D isotope enrichment versus the δ18O value. The value of “d” is a relatively important parameter concerning the climate of an area. The values of groundwater in the study area in the period I range from 10 and 15.1‰; period II range from 9.38 to 14.02‰; in period III of 5.32‰ in Mudal, indicating that the range of “d” values in Mudal is relatively higher, in all seasons. Clapar springs do not show d excess in period III. In general, the value of d gets lower over time.
In general, $\delta D$ excess is influenced by air mass which is usually different, where the dry season tends to be dry, while the rainy season has humid air [1]. In rural areas, the isotopic exchange between rainwater and humidity can slightly shift $d$ [39]. However, the $d$ value was not significant for the springs in the study area. However, the $d$ values in the two springs in the two seasons varied, not showing a great difference. This less difference can be interpreted that the humidity in the air during the dry and rainy seasons is not much different. The evapotranspiration conditions can occur quite intensively in the two seasons [33].

In dry conditions, evapotranspiration as a controller for groundwater recharge is usually relatively reduced, while in the rainy season / humid air, evapotranspiration is greater [1]. In addition, many plants are dormant in the dry season in the dry season, while the plants are more developed in the rainy season. Thus, the differences in evapotranspiration and humidity conditions in all seasons were not significant.

In addition, large $d$ values usually occur in high permeability rocks or thin soil, resulting in rapid infiltration [1]. This rapid infiltration causes groundwater to experience no / less evapotranspiration. Mudal spring has a character like this, supported by many fractures, cracks, and dissolving cavities in the limestone that consist of the aquifer of these springs. Mudal aquifers are examples of karst aquifers that usually have conduit characteristics and can have underground rivers due to interconnected conduits. However, a large shifting in $d$ values can occur in both the Jonggrangan and Old Andesite Formations aquifers.

5. Conclusion
This groundwater hydroisotope study was carried out on two selected springs in the West Progo Hills, namely the Mudal springs, which emerged from the limestone of the Jonggrangan Formation and the Clapar springs from the volcanic breccias of the Old Andesite Formation. Both springs have stable isotope content characteristics, relatively stable, with insignificant changes with time and season. Mudal springs have an isotope that tends to be light, indicating deep aquifer or high elevation recharge based on their absolute value. Meanwhile, Clapar spring shows heavier isotopes, which come from shallow aquifers with a mixing/evaporation process and are more influenced by the season. Based on the range value of $\delta^{18}O$ and $\delta D$, Mudal springs contain isotopes that are less affected by seasonal changes, while Clapar springs are seasonal. The range value of $\delta D$ in both springs is slightly - totally change, which means that it changes due to the change of seasons even though it is small. Based on the season, $\delta D$ enrichment in Mudal shows uncertainty, while Clapar spring has a medium-large change character. Meanwhile, the “$d$” value varies independently of the season, which can be interpreted that the climate conditions during the dry and rainy seasons in the study area are not much different.

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