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

By Listiyani Retno Astuti

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

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 shallow aquifer with mixing / evaporation processes and more influenced by the season. Meanwhile, the range value of δD in the two springs show slightly - totally changes, indicating that the D content also changes due to seasons, although it is small. The δD enrichment shows the medium - big 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.

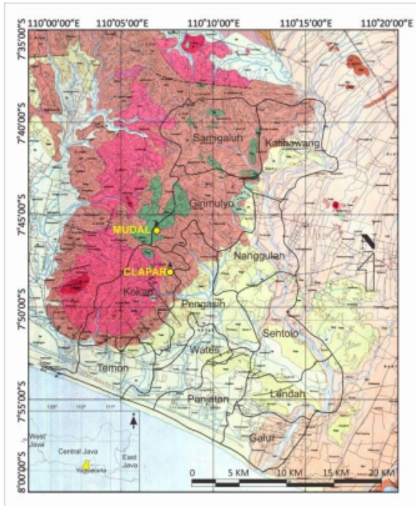
1. Introduction

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 (hydroisotopes). Isotope analysis is useful to aid in the interpretation of groundwater flows as well as aid in its genetic interpretation. The results of groundwater hydrochemical analysis can be verified by isotope analysis so that it will produce a better interpretation of the groundwater flow system. In addition, isotope studies have also been developed using the 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 isototope analysis is useful for knowing the origin of groundwater and interpretation of catchment areas. In addition, stable isotope data can also be used for analysis of hydrochemical processes, due to seasonal changes [6]. This paper intends to discuss the characteristics of the stable isotopes ^{18}O and D, particularly in relation to seasonal changes in the West Progo Hills area. The case study in this case was carried out on the Mudal and Clapar springs which are located in the central part of the West Progo Dome physiography [7].

Mudal spring is at an elevation of 664 meter 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].



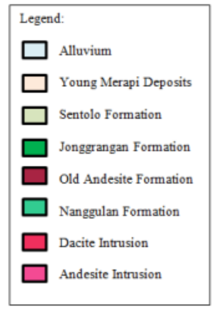


Figure 1. Location of Mudal and Clapar springs in Geological map [8]. Mudal spring is located at Jonggrangan Formation, while Clapar at Old Andesite Formation.

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 is composed of conglomerates, tuff marl and limestone sandstones with lignite inserts, layered limestone and coral limestone. Meanwhile, the Old Andesite Formation is composed of andesite breccias, tuffs, lapilli, agglomerates and intercalation of andesite [8]. Mudal spring appear in the Jonggrangan Formation rocks, while Clapar spring appears in the Old Andesite Formation (Figure 2).

Figure 2. Mudal spring appear in the Jonggrangan Formation (top), while Clapar spring appear in the Old Andesite Formation (bottom).

Although West Progo Hills is classified as a non-groundwater basin [10], there are many springs can be found even though they have generally small discharge. 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], in addition to lineament factors [12]. Geological lineaments play a role in the occurrence of springs, where the emergence of these springs is greatly influenced 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 debits and represent the aquifer of the Jongrangan Formation, while the Clapar springs are medium / large enough and represent the Old Andesite Formation.This research focuses on isotope studies, but in the field, some groundwater hydrochemical data is also taken together with isotope sampling.

Groundwater samples from both springs were taken in three periods, namely 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 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 8 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.

Table 1. Precipitation data in research area (mm/month) [13-15].

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), which is located in Pasar Jumat, South Jakarta. The isotope content analyzed is oxygen-18 (^{18}O) and hydrogen (^{2}H), known as deuterium (D) isotope. 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. Isotope ratios were measured by a mass spectrometer 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 $\delta^{18}O$ and ± 1‰ for δD [3]. Furthermore, the results of the stable isotope test were analyzed to determine the changes as well as the interpretation of 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 $\delta^{18}O$ 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 with 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 be used to determine age, while stable isotopes are useful for determining water genetics [17].

Isotopes contained in water, namely hydrogen atoms (^{1}H, ^{2}H, ^{3}H) and oxygen atoms (^{16}O, ^{17}O, ^{18}O) often be used in hydrogeological studies [18,19]. The abundance of ^{1}H isotope is about 99.985%, ^{2}H 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 the form of compounds $^{1}H_2{}^{18}O$ and $^{1}H^{2}H^{16}O_2$ [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 as an indicator for 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, determination of groundwater infiltration zones [5,25-28], as well as studies of mixing groundwater from different sources [29]. Even, 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 for 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, in places further away from the sea and in places of higher elevation. Every 100 m elevation increase, ^{18}O in rainwater will decrease of 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 δD 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 waterline (GMWL) was known as $\delta D = 8\delta^{18}O + 10‰$. Rainwater tends to contain the stable isotopes $\delta^{18}O$ and $\delta^{2}H$ 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 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 $\delta^{2}H = 7.978\ \delta^{18}O + 8.423$ ‰. 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 the West Progo area is not yet available.

To see the influence of climate / rainfall, regression line relationships $\delta^{18}O$ and δD 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 then the groundwater is affected by local climate (originating from local precipitation) or by topographic effects [1].

4. Result and discussion

4.1. Spring characteristic

Mudal Springs emerge from the limestone aquifer of Jonggrangan reef, supported by large porosity, as well as large rock permeability. The porosity developed as fracture and channel types. Jonggrangan limestone is dominated by thick to massive layered coral limestones. Around the Mudal springs this reef limestone outcops show white to brownish white colour, 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 discharge 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 large flow that develop as runoff / rivers. This spring is a parennial spring although has big change of discharge over season. Based on its temperature, Mudal is classified as normal spring. The physico-chemical 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 Old Andesite Formation, which are supported by fracture and sheeting joints porosity with moderate intensity and also controlled by low - medium permeability. Clapar springs have fracture type of springs. The discharge of springs usually small (stagnant) - medium flow rate, with small fluctuation of discharge. These springs can be classified as normal springs based on their temperature of water. The physico-chemical data of these springs show the temperature of 23.7 – 24.5^{o}C, with pH range of 7 – 8.2, TDS of 75 – 97 ppm and EC of 157 – 185 µS /cm.

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

Stable isotope content data in Mudal and Clapar spring water can be seen in Table 2 below. Furthermore, the absolute value and range value of the isotope content 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 δD. 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.

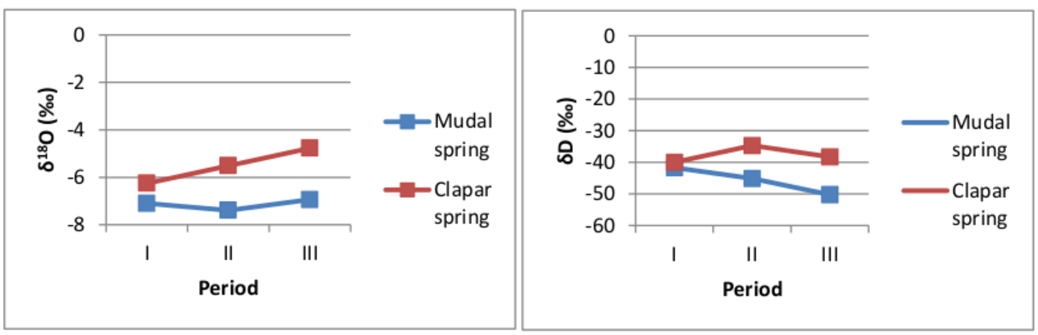


Figure 3. The development of stable isotope content over the three test periods.

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

Variable	Spring	δ^{18}O (‰)	δD (‰)
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
	Clapar	no effect	higher when dry

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

Compared to Clapar springs, Mudal springs contain lighter ^{18}O and D isotopes in the three periods studied. This 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
	$\delta^{18}O$ (‰)	δD (‰)	$\delta^{18}O$ (‰)	δD (‰)	$\delta^{18}O$ (‰)	δD (‰)	
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 run off or other source / 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 water from other sources or run off.

The interpretation of water sources in the Mudal and Clapar springs is also supported by physico-chemical data from the groundwater. Mudal springs release water from deep aquifers characterized by cooler temperatures, according to other researchers that higher temperature may be sourced from mixing between 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 TDS and EC values which are much greater in the water from the Mudal springs than Clapar.

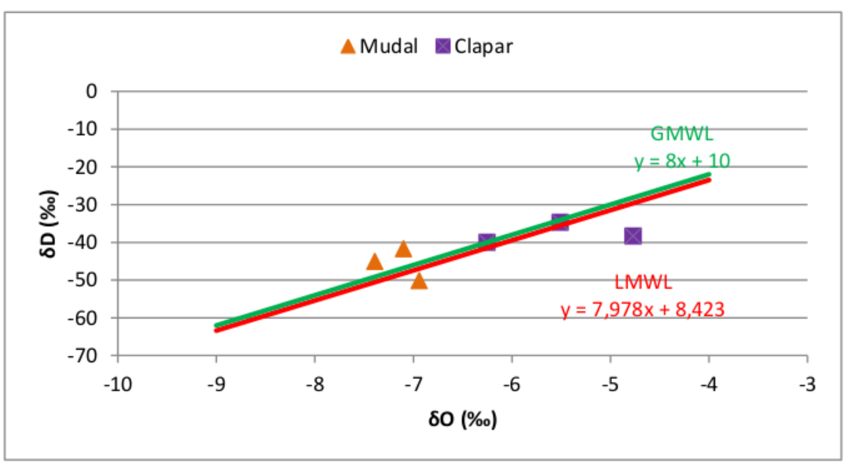


Figure 4. The relation of $\delta^{18}O$ and δD in groundwater of springs.

4.2.2. Range value of $\delta^{18}O$ 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 $\delta^{18}O$ range value in all periods, it appears that the groundwater from Mudal springs has isotopes $\delta^{18}O$ is light, while the Clapar springs have value $\delta^{18}O$. 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 quite affected by changes in the season. Referring to the opinion of 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 $\delta^{18}O$ for Mudal spring did not show any clear changes. This means, the ^{18}O isotope content in Mudal springs is relatively stable and less affected by the amount of precipitation. This also indicates that the Mudal springs are supported by relatively deeper aquifers.

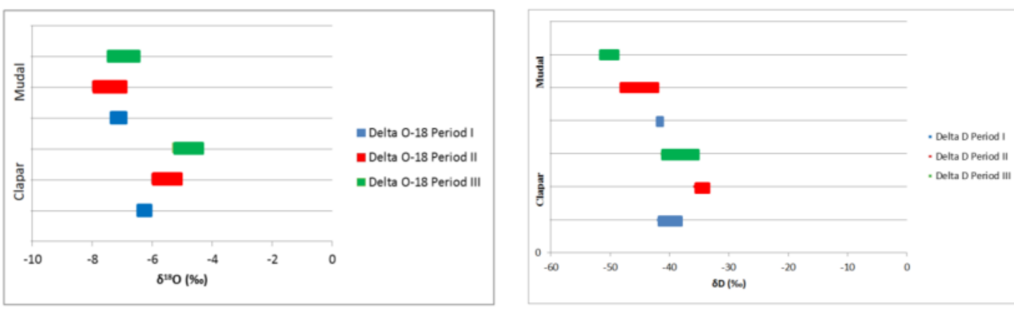


Figure 5. The values range $\delta^{18}O$ and δD for Mudal and Clapar springs. The overlaping values indicate the similarity of δD in different seasons.

Table 5. Value range interpretation $\delta^{18}O$ and δD.

Water springs	δ18O	δD	Analysis
Mudal	In short, some overlap	Short and long, shifted	$\delta^{18}O$ and δD are relatively stable / light, less affected by seasonal changes
Clapar	Short - long, shifted, enrichment	Short-a bit long, overlap especially in the rainy season	$\delta^{18}O$ and δD relatively stable / heavy, affected by season, intensive evaporation / mixing

Change δD of groundwater usually occurs due to isotopic exchange with minerals containing hydrogen, such as gypsum and clay minerals [34,35]. However, data doesn't support for this exchange. The δD in these two materials is not yet known, so the cause of the δD change 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 δD, 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 δD changes*

The process that occurs related to the seasonal effect can be assessed based on the $\delta^{18}O$ against δD 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 the enrichment of meteoric water isotope content has not been clearly seen [38]. However, the climatic influence in this dry season can be seen from the presence of d-excess [1]. Further reasearch 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 that is smaller than the LMWL gradient indicates a variation in the rate of evaporation. In addition, it is possible that evaporation will 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 δD or $\delta^{18}O$ enrichment effect. O-18 isotope enrichment during the rainy season relative to the dry season occurs in Mudal springs, while δD 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 as a result of water-rock interaction. This was also supported by the TDS and EC values of groundwater in the Mudal springs which were much greater than the Clapar springs, both during the rainy and dry seasons. Enrichment of $\delta^{18}O$ can be caused by carbonate minerals [35,37]. Meanwhile, the δD enrichment of Clapar springs occurs indicating that seasonality affects the content of these stable isotopes. Season has an effect on the evaporation process which can enrich the isotopic content of groundwater.

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

Table 6. The δD enrichment in the dry season relative to δD in the rainy season.

Spring	δD dry (Period II)	δD 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 medium - large δD enrichment (>5‰), but not related to seasonal changes. The Clapar springs undergo moderate - large changes due to enrichment during the dry season. The δD enrichment in the Clapar springs in the dry season shows a seasonal effect on the D isotope of groundwater. This is confirmed by a shift in δD values can occur due to seasonal changes [2].

A spring that has δD enrichment >5‰ is classified to have a big 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 taken into account, then 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 differences in temperature. Usually, the temperature effect is related to the elevation of an area. However, in this study it is difficult to study the effect of elevation, 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 that it was good $\delta^{18}O$ nor δD varies considerably, both in absolute value and in range. The data that are not much different are 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].

$$d = \delta D - 8\delta^{18}O \quad (1)$$

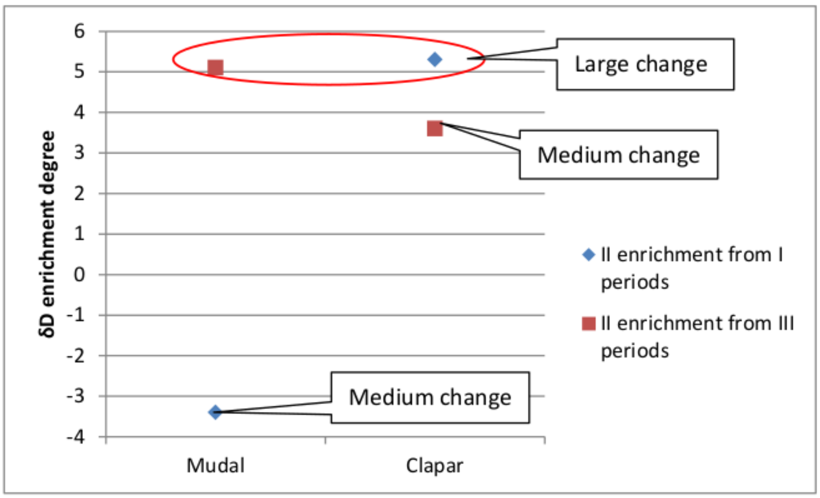


Figure 6. D-enrichment of groundwater in Mudal and Clapar springs.

Table 7. The value of the δD-excess of groundwater.

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 $\delta^{18}O$ value. The value of "d" is a relatively important parameter in relation to the climate of an area. The values of groundwater in the study area in 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, δD 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 the value of 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 strong difference. This less difference can be interpreted that the humidity in the air during the dry and rainy seasons is not much different, as well as the evapotranspiration conditions that 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, in the dry season, many plants are dormant, while in the rainy season the plants are more developed. 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 the large number of fractures, cracks and dissolving cavities in the limestone that consist the aquifer of these springs. Mudal aquifers are examples of karst aquifers which usually have conduit characteristics and have the potential to have underground rivers due to interconnected conduits. However, 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 which emerged from the volcanic breccias of the Old Andesite Formation. Both springs have the characteristics of stable isotope content of groundwater which is relatively stable, with insignificant changes with time and season. Based on its absolute value, Mudal springs have an isotope that tends to be light, indicating deep aquifer, or high elevation recharge. 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 δD, Mudal springs contain isotopes that are less affected by seasonal changes, while Clapar springs are seasonal. The range value of δD 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 season, δD 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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