Groundwater flow model in the center of West Progo Dome, Kaligesing, Purworejo, Central Java and its surrounding area, based on hydrochemical and isotopic

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Groundwater flow model in the center of West Progo Dome, Kaligesing, Purworejo, Central Java and its surrounding area, based on hydrochemical and isotopic characteristics

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Abstract: Groundwater studies were carried out in the center of the West Progo Dome, at Kaligesing, Purworejo District, Central Java , and its surrounding area, with an emphasis on hydrochemical problems. As a water-scarce area, groundwater studies are urgently needed in this area. This research is intended as a hydrogeological study with the aim of knowing the conceptual groundwater flow model in the study area. The method used is a field hydrogeological survey as well as hydrochemical and natural isotope analysis supported by chemical and groundwater isotope data. Less clear hydrochemical evolution indicates that the process of groundwater flow is dominant in the local flow system. Groundwater facies is dominated by bicarbonate type, neutral pH, relatively low total dissolved solid (TDS), and electric conductivity (EC), and influenced by season or rainfall. The dominant hydrochemical processes in the groundwater system are leaching, ion exchange, sulfate reduction, and dilution. Groundwater facies is determined by the rock minerals marked by differences in hardness and TDS. Whereas, stable isotope contents of groundwater vary from light to heavy. Springs with light isotopes show the circulation of deep groundwater flow or from a relatively high recharge zone, either locally or from other places around it. Isotopic enrichment in all seasons can occur due to evaporation or mixing with surface water that has undergone previous evapotranspiration, indicated by increasing of heavy isotopes or δD-excess (d) of groundwater. There are two types of groundwater flow patterns, namely shallow and deep groundwater flow patterns. Shallow groundwater is characterized by heavy isotopes, shifted with relatively small d. Deep groundwater circulation pattern is characterized by a consistent, light δD value and appreciable d.

Keywords: Groundwater, flow system, pattern, hydrochemistry, stable isotopes

Abstrak: Corak aliran air bawah tanah telah dipelajari di pusat Kubah Kulon Progo, di Kaligesing, Purworejo, Jawa Tengah dan sekitarnya, oleh analisis hidrokimia dan isotop. Sebagai kawasan yang kekurangan air, kajian air bawah tanah diperlukan di daerah ini. Penyelidikan ini bertujuan sebagai kajian hidrogeologi dengan tujuan mengetahui model aliran air bawah tanah secara konseptual di kawasan kajian. Kaedah yang digunakan adalah tinjauan hidrogeologi lapangan serta analisis isotop hidrokimia dan semula jadi yang disokong oleh data kimia dan sampel isotop air bawah tanah. Evolusi hidrokimia tidak jelas menunjukkan proses aliran air tanah berada dalam sistem aliran tempatan. Fisi air bawah tanah dikuasai oleh jenis bikarbonat, pH neutral, TDS (total dissolved solid) dan EC (electric conductivity) yang rendah dan dipengaruhi oleh musim atau hujan. Proses hidrokimia dominan adalah larutan, pertukaran ion, pengurangan sulfat, dan pencairan. Air bawah tanah mengalir dalam akuifer Jonggrangan dan Old Andesite. Jenisnya ditentukan oleh mineral-mineral batu yang ditandakan dengan perbezaan kekerasan dan TDS. Sementara itu, kandungan isotop yang stabil air bawah tanah berbeza dari ringan ke berat. Mata air dengan isotop ringan menunjukkan peredaran aliran air bawah tanah atau dari zon penyerapan semula yang tinggi, sama ada dari dalam atau dari tempat lain di sekelilingnya. Pengayaan isotop pada semua musim boleh berlaku disebabkan oleh penyejatan atau pencampuran dengan air permukaan yang telah mengalami evapotranspirasi terdahulu, ditunjukkan oleh peningkatan isotop berat atau δD-berlebihan (d) air bawah tanah. Terdapat dua jenis corak aliran air bawah tanah, iaitu corak aliran air bawah tanah yang cetek dan mendalam. Air bawah tanah cetek dicirikan oleh isotop berat, beralih, dengan d relatif kecil. Corak peredaran air bawah tanah mendalam dicirikan oleh nilai δD yang konsisten, ringan dan d air bawah tanah yang cukup besar.

Kata kunci: Air bawah tanah, sistem aliran, corak, hidrokimia, isotop stabil

INTRODUCTION

The study area is well known as a hard water area (Listyani *et al*., 2018). Landform in this area shows high elevation of steeply hills, with wet tropical climate. The weather shows that the air temperature generally ranges from 22 °C – 32 °C, with an average temperature of 26 °C. The evaporation is moderate in rainy season and increases when dry season. Rainfall rates is high (300 – 400 mm/month) during the rainy season and moderate (100 – 150 mm/month) in the dry season (Meteorology Climatology and Geophysics Council, 2018), or 3000 – 4000 mm/year (Putranto & Aryanto, 2018).

The problem of water resources is often an important thing that must be considered today. Various surface and groundwater problems are examined to obtain sufficient and good quality water resources. Surface water that is too much-flooded needs to be addressed (Mera & Rantoso, 2019), but the presence of too little groundwater is also a serious problem. West Progo Hill is an area that often suffers from water shortages, therefore water resources investigations need to be carried out in this area. As hard water area, this region consists of colluvium and fractured rock aquifers. Thus, a study on groundwater potential is important in this area.

Groundwater studies have developed rapidly along with the need for groundwater in various regions. This study is important to be carried out in order to understand water resources through various studies. This paper is the result of hydrogeological mapping activities with the aim of understanding the system and pattern of groundwater flow in the West Progo area, especially in the central part. The results achieved are groundwater flow models that are known based on hydrochemical and stable isotopes of ^{2}H (deuterium, D) and oxygen-18 (^{18}O) characteristics. Isotope analysis has been widely developed in hydrogeological studies in many places. Hydroisotope method using ^{2}H and ^{18}O has been chosen because of its relatively low cost of analysis (Irawan, 2009; Alam *et al.*, 2014). The advantage of using the stable isotopes δ^{18}O and δ^{2}H compared to other isotopes is that the content of these stable isotopes in rainwater shows a linear relationship in the form of a global meteoric water line (Satrio & Sidauruk, 2015).

Although the research area is a hard water region (Listyani *et al.*, 2018, 2019), groundwater hydrochemical analysis can assist to determine groundwater flow systems. This analysis can be done by determining the groundwater chemical facies/types. Aquifer hydrogeochemical characteristics are also determined to identify groundwater flow patterns and the interpretation of hydrochemical processes. Isotope analysis is useful to help interpret groundwater flow patterns. The results of groundwater hydrochemical analysis can be verified by isotope analysis so as to produce a better interpretation of the groundwater flow system.

Many researchers have conducted groundwater research using hydrochemical methods in an area, including by utilizing groundwater chemical composition to determine their behavior in aquifers (Alam *et al.*, 2014, 2019; Putranto *et al.*, 2017; Putranto & Aryanto, 2018; Setiawan *et al.*, 2020a, 2020b). In addition, isotope studies have also been developed in many groundwater basins, specifically using stable isotopes of ^{18}O and ^{2}H (D). Various hydrochemical and isotope methods have been developed in various groundwater basins but have not been widely used in hard water areas or not potential groundwater basins. For this reason, the author is interested in studying groundwater in hilly areas, considering that this area is a groundwater basin that is lacking in potential as there has not been much in-depth hydrogeological (hydrochemical and hydroisotope) research in this area.

The area of research is administratively included in the area of Kulon Progo District, Special Region of Yogyakarta and Purworejo District, Central Java (Figure 1). Most of the western part of studied areas are included in Kaligesing Subdistrict, Purworejo District, while the eastern part are included in Girimulyo Subdistrict, West Progo District. The land use of the areas is dominated by forest, garden, brush and empty land (Putranto & Aryanto, 2018), while settlements are only found rarely and locally.

By conducting chemical and natural isotope analysis, this study seeks to present a groundwater flow model in areas that are often referred to as non-groundwater basins, particularly in the Kulon Progo Dome. So far, studies on natural isotopes have never been carried out in this area. This isotope study is very important to help understand groundwater flow systems, as well as analysis of groundwater level mapping and hydrochemicals.

MATERIAL AND METHODS

Field sampling and laboratory testing

The groundwater study began by conducting hydrogeological mapping in the field with observations of 35 wells and 40 springs. Each sample was taken twice, during the dry and rainy seasons. The groundwater samples were taken at selected springs, with 14 samples to be tested for chemical and stable isotope contents. Those samples represent the Old Andesite and Jonggrangan formations, where each formation is represented by 7 samples during each season. All samples were taken from large discharge springs because springs are a natural discharge, and thus can characterize the origin of groundwater flow. Dug wells are rare and unevenly distributed, as such they are less representative to be tested in the laboratory. However, observations were made on dug wells to determine groundwater levels and their quality. Monitoring has been done at least twice in a season. The sampling made in June 2017 represents the dry season and in November 2017 represents the rainy season. Some field photos are shown in Figure 2.

Several parameters of the physical/chemical characteristics which were measured in the field include temperature (T), acidity (pH), total dissolved solid (TDS), and electric conductivity (EC). These parameters were measured using a thermometer, and Hana portable test kit (pH-meter, EC-meter and TDS-meter). The groundwater samples were filtered using 0.45 syringe and put in a 500 ml polyethylene bottle for anion and 500 ml for cation analyses. The groundwater was acidified by 0.1 N HCl especially for cation samples to prevent precipitation in the bottles.

The physical/chemical parameters of the spring water samples were tested in BBTKLPP Laboratory, Yogyakarta, Indonesian Ministry of Health. The test was carried out using the test method from the Indonesian National Standard (SNI) 2004-2009, in-house method and the 2012 APHA. The instrument used was the ion chromatography / spectrophotometer. The major ions were determined using chromatography and spectrophotometer equipment.

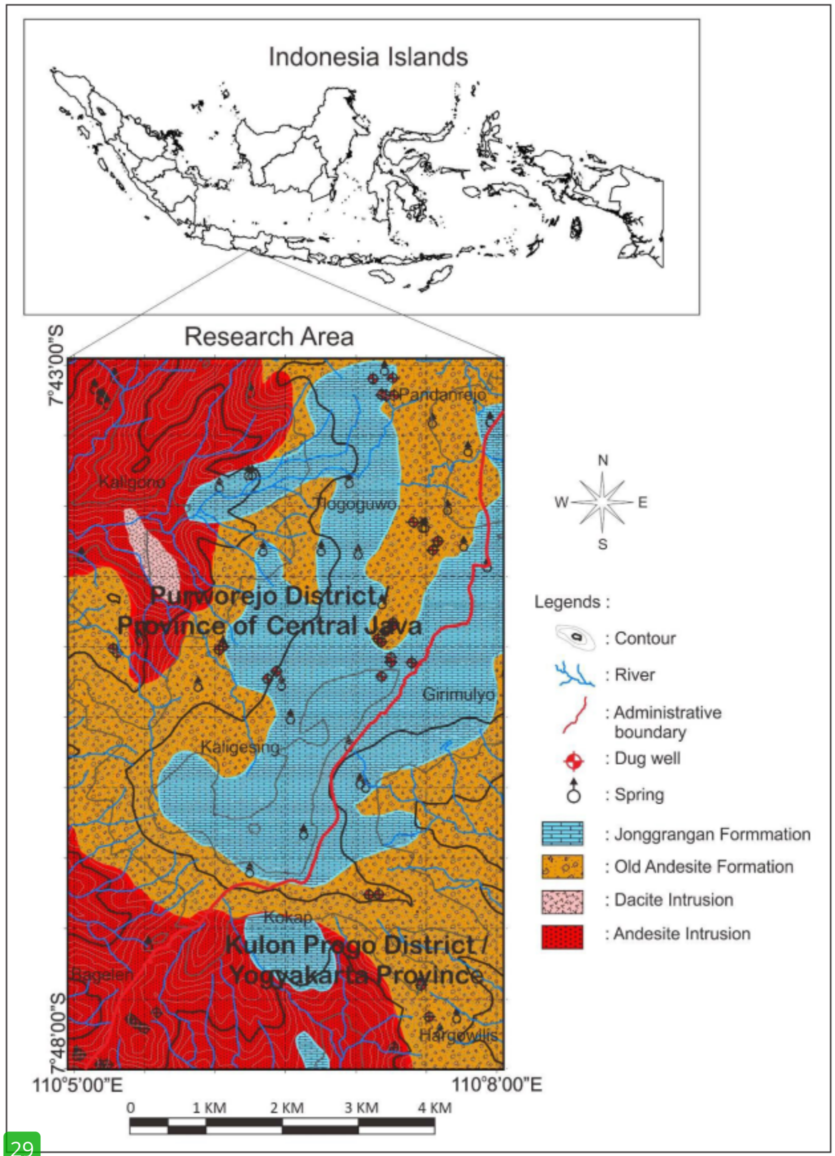

Figure 1: The location index map of the study area.

According to Yuan *et al.* (2017), the results can be ideally used with charge balance error less than 5%.

Whereas, the stable isotopes ^{18}O and ^{2}H are present in water in the form of $^{1}H_2{}^{18}O$ and $^{1}H^{2}H^{16}O$ compounds (Satrio *et al.*, 2017). These two isotopes are very sensitive to physical processes such as evaporation and condensation, therefore to prevent this the sampling was carried out in the following manner.

a. The 30 ml water sample was put in an airtight (polyethylene) bottle by inserting the bottle into the water source.
b. Avoid the formation of air bubbles in the sample by inserting the sample slowly.
c. After the bottle is completely filled and there is no air bubbles, the bottle is tightly closed until it is airtight (Satrio *et al.*, 2017). To avoid interaction with the atmosphere and evaporation, the plastic bottles are equipped with an inner cover (Satrio & Sidauruk, 2015).

Groundwater stable isotope test was conducted at the Hydrology Laboratory, Center for Isotope and Radiation Application (PAIR) - National Nuclear Energy Agency (BATAN), 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. Isotope ratios were measured by a mass spectrometer and the results were referenced against the SMOW standard.

Figure 2: Clockwise from top left: Sikantong, Mudal, Clapar springs and andesite lava outcrops in Clapar. Both Sikantong and Mudal springs discharge water from the Jonggrangan Formation, while the Clapar Springs are found in the Old Andesite Formation.

The internal standards were calibrated using V-SMOW with analysis accuracy of ± 0.1 ‰ for $\delta^{18}O$ and ± 1 ‰ for δD.

Hydrochemical analysis

Geological interpretation can be done from the quality data of groundwater from springs. The parameters analyzed include major ion and other parameter (pH, temperature, TDS and EC) in the field. The principle of this interpretation is based on the relations of the constituent ions of groundwater and is very useful for the purpose of analysis and synthesis (Swanson *et al.*, 2001; Yidana *et al.*, 2010). In addition, the groundwater characteristics are influenced by aquifer types (Harun *et al.*, 2019).

Groundwater chemical analysis begins with reviewing the validity of groundwater chemical data using the ion balance method. Further analysis was carried out using several methods including the Kurlov and Chadha classification method (Ako *et al.*, 2012), the Piper and Durov interpretation method (Lloyd & Heathcote, 1985), the Hiscock exploration method (Hiscock, 2005), the Gibbs diagram (Putranto *et al.*, 2017) and the determination of the saturation index. Scatter plots of ions in groundwater are also carried out to see the effect of rocks on groundwater quality and their relationship with elevation and hydrochemical processes (Listyani, 2019).

Stable isotope analysis

Values $\delta^{18}O$ and δD and their range values can be used to see groundwater genesis (Satrio & Sidauruk, 2015). The content of this stable isotope in rainwater shows a linear relationship in the form of the global meteoric water line (GWML). Deviation from this line can be assessed to estimate groundwater genetics. The distribution pattern of stable isotope contents can be analyzed to see the possibility of an isotopic evolutionary process in the groundwater flowing process in a groundwater basin. The relationship of stable groundwater isotope content to elevation and TDS can also be analyzed to determine the influential hydrochemical processes. In addition, an analysis of the enrichment of stable isotopes can be carried out to see the effects of seasonal changes on the content of these isotopes.

Evaluation is carried out based on compilation of field data, laboratory test results and assisted by some secondary data related to the substance of the study. The evaluation is based on a number of graphs used in the analysis as well as several maps generated from field and laboratory data in groundwater.

Data verification

Primary data that have been obtained are then verified using statistical tests. The statistical method used in this study is the correlation regression method to see the relationship between two variables, as well as the average difference test to see whether there are differences in a variable in different aquifer systems (Jonggrangan Formation vs Old Andesite Formation).

RESULTS AND DISCUSSION

Geology and hydrogeology of the study area

According to Van Bemmelen (1949, in Listyani *et al.*, 2018) physiographic zoning division, the study area is included in the Dome and Hills Zone of the Central Depression. West Progo Hills is a dome-like area. West Progo Hills turns to the northwest and continues with the South Serayu Mountains.

Stratigraphically, the study area consists of Old Andesite and Jonggrangan formations (Figure 1). The Old Andesite Formation is composed of volcanic rocks such as andesite breccias, tuffs, lapilli, agglomerates and intercalation of andesite lava. Andesite intrusion is also found, composed of hyperstene andesite to hornblende andesite augite and trachyandesite. Meanwhile, the Jonggrangan Formation is composed of layered limestone and coral limestone dominantly, tuff marl and limestone sandstones.

Geology in the study area is dominated by volcanic material such as andesite breccias and andesite lava flows. These material was formed by the existence of ancient volcanic activity during the Tertiary period and is impermeable. These material is not able to store and flow water, thus the groundwater reserve in this area is very small. The presence of groundwater in this area is often found in deep layers and only found in rock fractures. Meanwhile, rocks from the Jonggrangan Formation in the study area are also dominated by compact limestones and provide groundwater through the crack pores in addition to the intergrain pores.

Hydrochemical and isotopes data

The results of chemical and isotope laboratory tests are shown in Tables 1 and 2. In accordance with the Kurlov classification, all groundwater studied was bicarbonate water, with variations in Ca, Na and Mg cations. The stable isotope test results show variations of -8.2 to 4.77‰ for ^{18}O and -50.2 to -34.7‰ for D.

Basic groundwater flow

The groundwater flow can be derived from groundwater table obtained from measurements in dug wells (Figure 3). The groundwater flow pattern is in line with the direction of the morphological slope, that is, from a high elevation area to a lower place. However, the groundwater level and the slope of the study area only correlated with a moderate level of relationship. This means that the magnitude of the slope does not always affect the groundwater flow pattern. However, steep slopes often control the formation of depressed springs so that the groundwater flow pattern leads to the local discharge zone in that area.

Groundwater flows from a higher groundwater level to a lower one, then comes out as a discharge in springs or dug wells. Groundwater flows locally from higher to lower areas near springs or dug wells. In general, groundwater flow patterns flow in various directions, including northwest, southwest and south / southeast. On

Table 1: Physical/chemical data of groundwater samples testing.

No	Parameter (mg/l)	S1	S4	S7	S11	S13	S14	S16	S17	S20	S21	S25	S26	S29	S39
		Munggangsari	Njuboh	Anjani	Pager tengah	Sikantong	Ngelo	Hulosobo	Mudal	Seplawan	Jatimulyo	Clapar	Durensari	Kaligono	Kaligesing
DRY SEASON															
1	Ca^{2+}	21,49	6,4	19,9	58,9	26,27	36,00	12,8	80,4	58,9	67,66	20,7	42,98	36,00	23,2
2	Na^{+}	22	6	10	13	11	5	15	6	6	8	21	25	21	18
3	K^{+}	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	Mg^{2+}	45,46	2,92	26,6	19,83	30,95	11,66	3,4	4,35	23,7	2,42	6,28	21,28	8,26	7,78
5	HCO_3^-	283,9	30	207,4	298,6	193,3	122	60,4	302,8	235,5	289,9	114,8	199,3	109,8	97,6
6	SO_4^{2-}	7	5	9	10	19	5	7	6	5	7	5	10	30	20
7	Cl^-	2	2,5	3,5	3	3	2,5	5	2	5	3	3	5	3,0	3,5
8	TDS	212	60	131	302	165	240	64	229	186	229	85	166	205	169
9	Hr.	240,11	27,97	158,81	228,55	192,57	137,81	45,94	218,84	244,42	179,07	77,5	194,7	123,87	89,9
RAINY SEASON															
1	Ca^{2+}	60,5	7,2	34,23	29,45	36,62	84,8	9,55	60,5	42,19	26,27	20,7	35,02	27,2	17,6
2	Na^{+}	21	9	6	8	6	6	12	5	5	5	20	19	17	14
3	K^{+}	1	<1	1	1	1	<1	2	1	<1	<1	2	1	<1	<1
4	Mg^{2+}	18,38	2,43	6,77	21,28	6,28	7,78	5,32	9,67	3,87	19,82	6,77	7,74	5,35	5,35
5	HCO_3^-	274,5	48,8	183	402,6	164,7	286,7	61	237,9	225,7	256,2	134,2	173,9	146,4	115,9
6	SO_4^{2-}	7	<1	7	13	14	7	8	6	6	6	6	8	10	9
7	Cl^-	3	3,5	3	2,5	4	2,5	5,5	4	2	2	4,5	2,5	1	1
8	TDS	206	35	128	234	126	217	50	198	216	215	89	123	91	71
9	Hr.	226,61	27,96	113,33	160,87	117,3	243,9	45,69	190,9	121,34	146,94	79,51	119,28	89,94	65,94

Table 2: Hydrochemical and stable isotopes laboratory tests results.

No	Code	Location	Hydrochemical Facies		Stable isotope			
			Dry	Rainy	Dry		Rainy	
					^{18}O (‰)	D (‰)	^{18}O (‰)	D (‰)
1	S1	Munggangsari	Mg-HCO$_3$	Ca, Mg-HCO$_3$	-7,4 ± 0,44	-42,1 ± 3,0	-4,96 ± 0,18	-45,7 ± 1,6
2	S4	Njuboh	Ca, Mg-HCO$_3$	Ca, Na-HCO$_3$	-7,25 ± 0,26	-45,5 ± 2,1	-7,83 ± 0,51	-42,7 ± 4,4
3	S7	Anjani	Ca, Mg-HCO$_3$	Ca-HCO$_3$	-6,84 ± 0,20	-42,2 ± 0,9	-7,37 ± 0,35	-48,3 ± 3,1
4	S11	Pagertengah	Ca, Mg-HCO$_3$	Ca-HCO$_3$	-7,34 ± 0,42	-43,1 ± 2,1	-5,84 ± 0,47	-46,9 ± 2,1
5	S13	Sikantong	Ca, Mg-HCO$_3$	Ca-HCO$_3$	-7,4 ± 0,18	-46,6 ± 1,3	-6,72 ± 0,22	-49 ± 2,2
6	S14	Ngelo	Ca, Mg-HCO$_3$	Ca-HCO$_3$	-6,6 ± 0,38	-39,3 ± 2,4	-7,69 ± 1,09	-46,3 ± 7,1
7	S16	Hulosobo	Ca, Na-HCO$_3$	Ca, Mg-HCO$_3$	-6,88 ± 0,20	-41,1 ± 1,5	-6,78 ± 0,31	-48,5 ± 1,1
8	S17	Mudal	Ca-HCO$_3$	Ca-HCO$_3$	-7,39 ± 0,42	-45,1 ± 3,1	-6,94 ± 0,39	-50,2 ± 1,5
9	S20	Seplawan	Ca, Mg-HCO$_3$	Ca-HCO$_3$	-6,72 ± 0,12	-38,9 ± 1,6	-7,22 ± 0,61	-44,6 ± 1
10	S21	Jatimulyo	Ca-HCO$_3$	Ca, Na-HCO$_3$	-7,39 ± 0,13	-41,2 ± 1,5	-5,17 ± 0,26	-41,9 ± 1,4
11	S25	Clapar	Ca, Na-HCO$_3$	Ca, Mg-HCO$_3$	-5,51 ± 0,32	-34,7 ± 1,0	-4,77 ± 0,34	-38,3 ± 3
12	S26	Durensari	Ca, Mg-HCO$_3$	Ca-HCO$_3$	-6,45 ± 0,21	-36,8 ± 1,7	-7,11 ± 0,15	-46,9 ± 3
13	S29	Kaligono	Ca-HCO$_3$	Ca-HCO$_3$	-6,45 ± 0,03	-38,8 ± 0,4	-7,8 ± 1,11	-45,6 ± 6,6
14	S39	Kaligesing	Ca, Mg-HCO$_3$	Ca, Mg-HCO$_3$	-6,8 ± 0,91	-41,3 ± 1,6	-8,2 ± 1,23	-47,1 ± 1

a large scale (narrower areas) it is still possible to flow in all directions following the local topography, for example to the north, east or west.

Groundwater flow pattern based on hydrochemical characteristic

Various analyses have shown that groundwater develops in bicarbonate facies, with variations in the main cations Ca^{2+}, Na^{+}, and Mg^{2+}. The physical/chemical properties of groundwater which include temperature, pH, total dissolved solids (TDS) and EC have little changes due to the change of seasons.

In general, the type of groundwater chemistry studied is relatively stable, meaning that it is not easy to change with seasonal changes. This groundwater facies is the initial phase of the evolutionary process in which these facies are a type of water chemistry that is typical for catchment areas. Based on the Chadha classification (Listyani, 2019), the main dominance of the carbonate type is Ca, Mg-HCO$_3$ and does not change in different seasons.

The main ion content is dominated by bicarbonate anions. This anion is the dominant ion affecting the groundwater TDS value. The high bicarbonate content is usually associated with rainfall. Meanwhile, the main cations contained in groundwater are Ca^{2+} and Mg^{2+}. The Mg^{2+} concentration increases during the dry season.

The composition of groundwater is dynamic. This composition can change due to a reaction between water and rock minerals. The process can take place during the groundwater infiltration process, during the process of flowing in the aquifer until it emerges as a spring (Chebotarev, 1955 in Domenico & Schwartz, 1990). Groundwater chemical composition in the study area also shows a dynamic nature, with some changes in chemical facies from one place to another. The difference of groundwater hydrochemical facies under study lies in the difference in the dominance of the main cation content.

The interpretation of groundwater flow patterns can be done based on the dominance of the main ions as follows.

1. Based on the main anion:

All groundwater samples show bicarbonate facies, meaning that groundwater flow patterns can begin (absorption zone) anywhere or end (discharge zone) in springs or dug wells anywhere.

2. Based on the main cation:

In accordance with the sequences of Goldich (1938, in Appelo & Postma, 2005), the pattern of groundwater flow can be interpreted successively from the facies of Ca → Ca, Mg → Mg → Ca, Na.

Thus, groundwater flow patterns can be interpreted to run from Ca-HCO$_3$ → Ca, Mg-HCO$_3$ → Mg-HCO$_3$ facies to Ca,Na - HCO$_3$ facies in the dry season (Figure 4) and from Ca-HCO$_3$ → Ca,Mg - HCO$_3$ facies to the Ca,Na - HCO$_3$ facies in the rainy season (Figure 5).

Groundwater in the Old Andesite Formation generally has a smaller primary ion content than in the Jonggrangan Formation. The main ion content is more in groundwater in the Jonggrangan aquifer, while silica content is more in the Old Andesite Formation. Ca content is greater in the Jonggrangan Formation. This cation can be obtained from dissolving carbonate minerals or minerals in andesitic rocks such as Ca-plagioclase.

Hydrochemical processes have been determined by Chada, Piper, Durov, Hiscock as well as Gibbs diagrams.

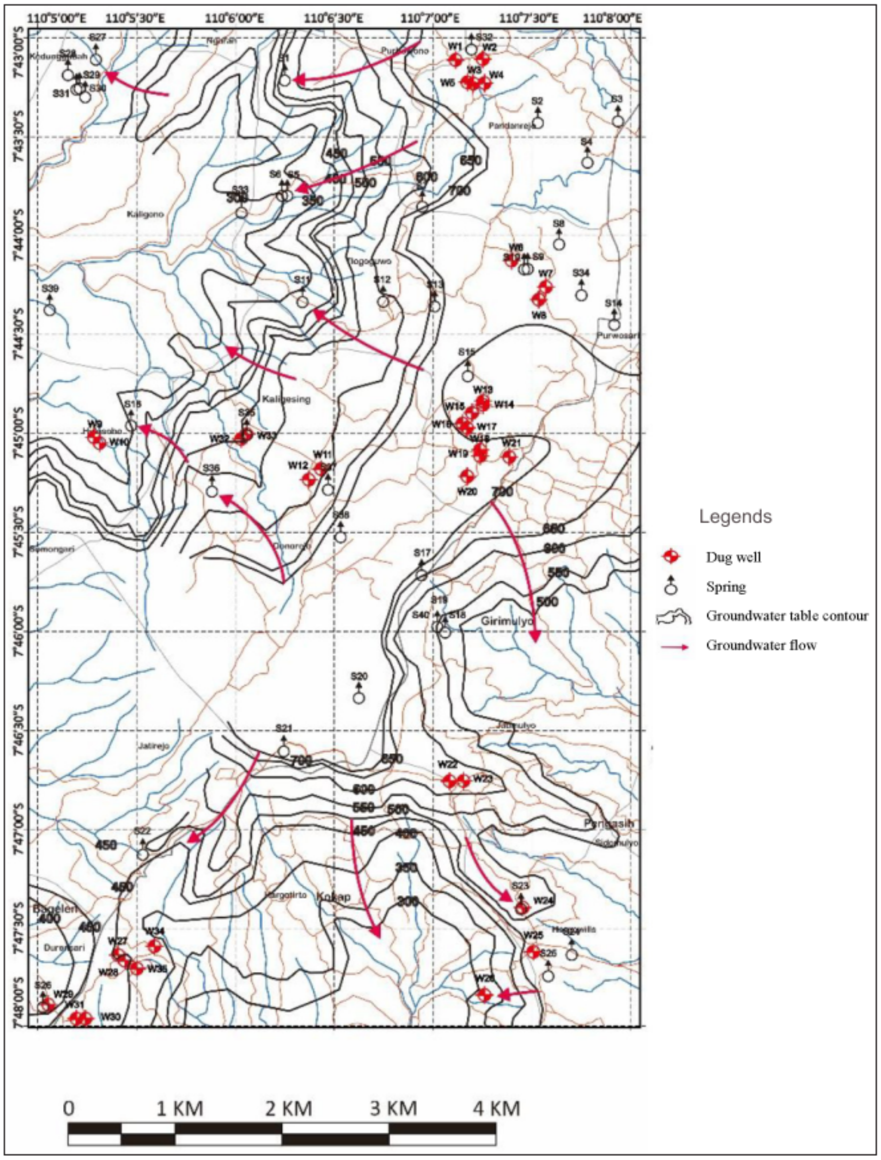

Figure 3: Map of the observation location and groundwater flow of the study area (Listyani *et al.*, 2019).

The results show that occur in groundwater flow systems in the study area are dominated by leaching, ion exchange, and sulfate reduction. In addition, the process of dilution by rainwater is also very important. The main ion content also shows the dominance of the influence of rocks dissolved in groundwater.

The rocks of the study area affect the groundwater chemical content studied through the weathering and dissolving minerals. Weathered primary silicate minerals generally turn into kaolinite and montmorillonite so they are easily dissolved in the groundwater system. The silica content in groundwater is relatively small. This silica grows larger in the Old Andesite Formation, showing a fairly large water-rock interaction as well, related to the large water-rock ratio in the rainy season.

Statistical tests have been carried out to determine the normality and homogeneity of the data. The results show that the groundwater hardness in the Jonggrangan Formation aquifer system is different from those in the Old Andesite Formation aquifer system, which is proven for the dry season data, but not significantly for the rainy season (Table 3; see data in Table 1). Hardness (Hr.) value is calculated from the formula Hr = 2.5 Ca + 4.1 Mg (Todd, 1949, in Listyani, 2019).

The statistical test of normality show that all TDS data in the dry and rainy seasons in the Old Andesite and

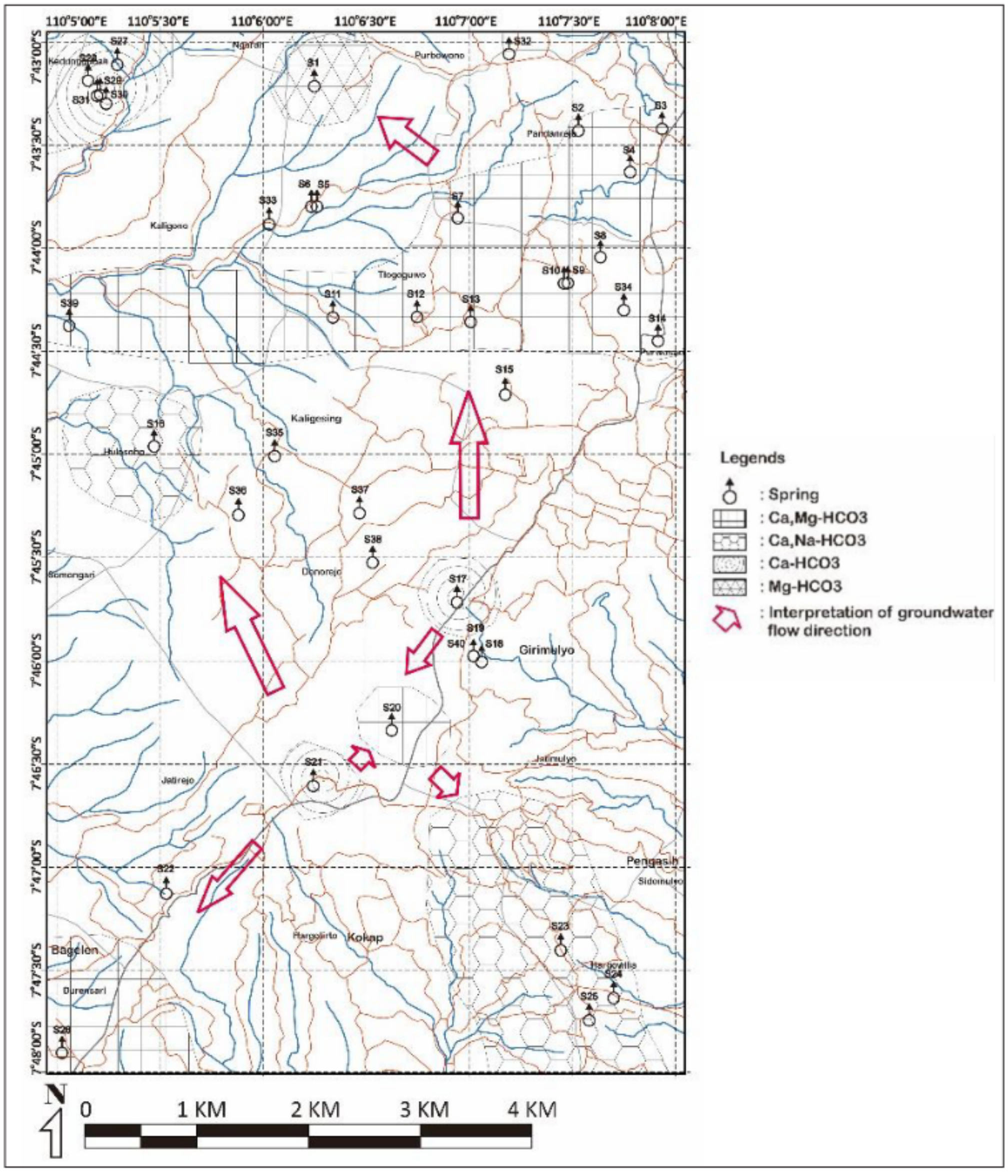

Figure 4: Interpretation of groundwater flow patterns based on hydrochemical facies in the dry season.

Table 3: Groundwater hardness statistical test results.

Season	Normality	Homogeneity	Different Test
Dry	Normal distribution	Homogeneous	There is a significant difference between groundwater in the Old Andesite and Jonggrangan Formations.
Rainy			There is no significant difference between groundwater in the Old Andesite and Jonggrangan Formations.

Table 4: The results of the groundwater TDS statistical test.

Season	Normality	Homogeneity	Different Test
Dry	Normal distribution	Homogeneous	There is a significant difference between groundwater in the Old Andesite and Jonggrangan Formations.
Rainy		Heterogeneous	

(Note: Data set for Table 3 & 4 is provided in Table 1)

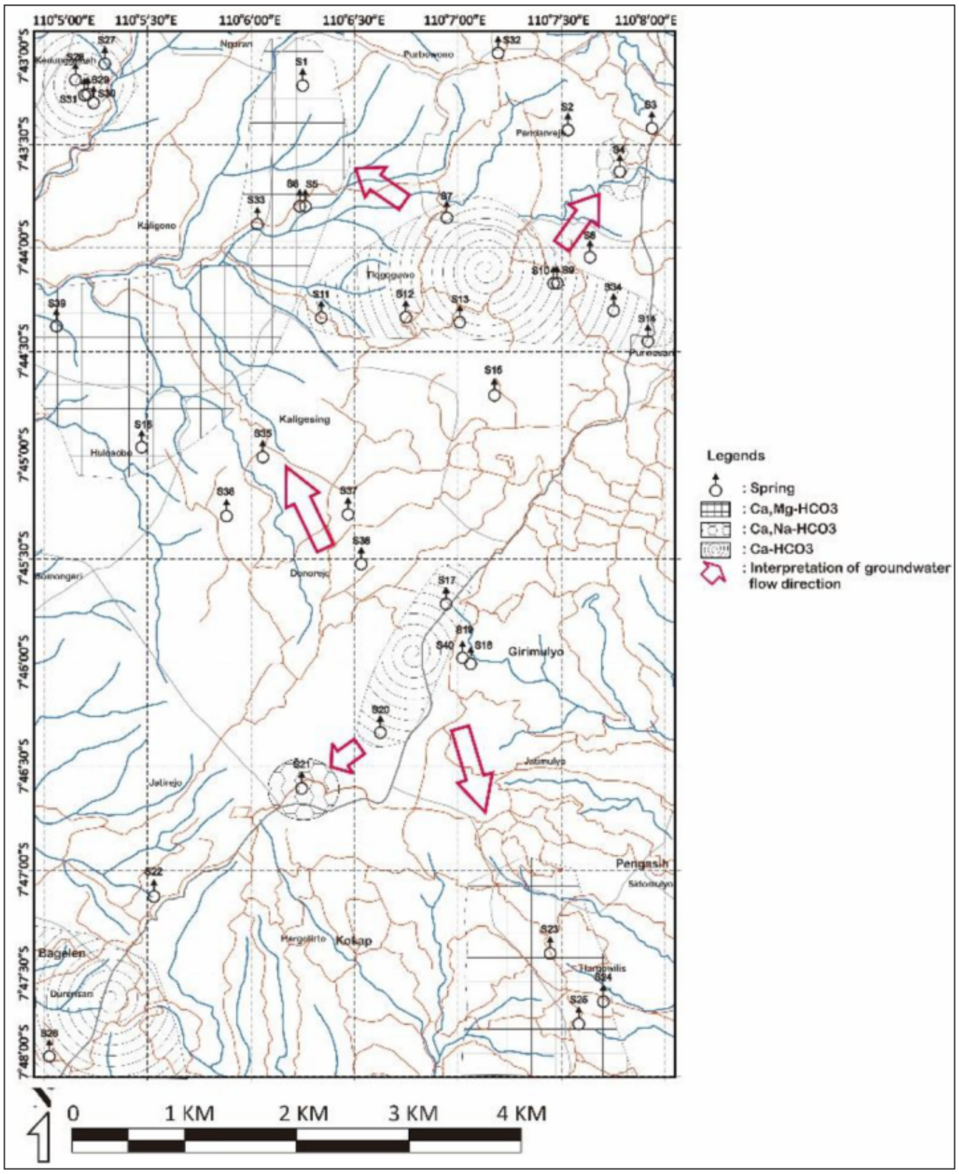

Figure 5: Interpretation of groundwater flow patterns based on hydrochemical facies in the rainy season.

Jonggrangan Formations are normally distributed (Table 4; see data in Table 1). Homogeneity test results in the dry season indicate that the data are homogeneous, but the data in the rainy season are not homogeneous. The difference in inhomogeneity in the rainy and dry seasons shows that the season affects the groundwater TDS. However, the results of different tests showed that groundwater TDS in all seasons had a significant difference between groundwater's TDS in the Old Andesite and Jonggrangan Formations. The results of this statistical test indicate that the groundwater TDS in the Jonggrangan aquifer system is different from that of the Old Andesite Formation aquifer system.

Groundwater flow pattern based on stable isotope characteristic

Groundwater in some springs has light or heavy stable isotopes. The content of stable isotopes marks the system of deep groundwater flow or elevation of infiltration water that occurs in high areas. S4 (Njuboh), S13 (Sikantong) and S17 (Mudal) springs which are at a high elevation are examples of springs that receive recharge from local areas with higher elevation. S17 (Mudal) spring also has the possibility of being supplied by infiltration water from other places, characterized by a very light δD (reaching -50.2‰). Meanwhile, springs S29 (Kaligono; marked with light $\delta^{18}O$) and S39 (Kaligesing; marked by light $\delta^{18}O$ and

D) at a lower elevation receive elevation from other higher elevation areas, for example from surrounding peaks/slopes.

High evaporation is marked by $\delta^{18}O$ which is experienced by S25 (Clapar) springs in the dry season and occurs in S1 (Munggangsari), S21 (Jatimulyo) and S25 (Clapar) springs in the rainy season. Some springs experience increased evaporation during the rainy season, marked by $\delta^{18}O$ values in the dry season and become heavier during the rainy season, including springs S11 (Pagertengah), S13 (Sikantong), S17 (Mudal), and S39 (Kaligesing). In addition to evaporation, this can also be caused by mixing with surface water that has evaporated before being infiltrated in groundwater.

If the groundwater regression line studied is close to the global meteoric water line (GMWL) and the local meteoric water line (LMWL), the groundwater is affected by the local climate or because of the topographic effects (Listyani, 2016). Groundwater regression lines adjacent to LMWL indicate that groundwater genetic originated from local precipitation (Figure 6a). Because this regression line is very close to the LMWL, enrichment of the isotope content of meteoric water is not yet clearly seen in this dry season. However, the presence of d-excess in the dry season is due to climate effects (Alam, 2014). Groundwater regression lines in the rainy season cross the LMWL line and do not resemble / close to LMWL (Figure 6b).

The regression line below the meteoric water line as shown in the figure shows isotopic enrichment (Alam, 2014). Several groundwater samples show plots below the LMWL which means that the groundwater has undergone isotopic enrichment, perhaps due to mixing with surface water/ runoff or because the evaporation process is quite intensive.

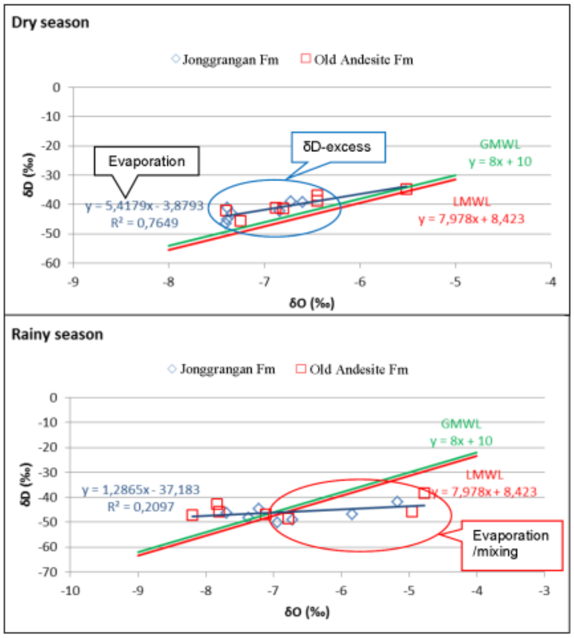

Figure 6: The relation between δD dan $\delta^{18}O$ of groundwater in dry (a) and rainy (b) seasons.

Heavy δD values in all seasons occur at S25 (Clapar) springs of -38.3‰. Supported by partial shifting in this δD, groundwater flow in the Clapar area is interpreted as shallow groundwater flow. The $\delta^{18}O$ and δD values which are heavier in the dry season than in the rainy season as in spring S29 (Kaligono) show more intensive evaporation during the dry season.

The total shifted of δD values marks shallow groundwater flow systems such as in springs S7 (Anjani), S16 (Hulosobo), S17 (Mudal), S20 (Seplawan), S26 (Durensari) and S39 (Kaligesing). In addition to these springs, all springs experience partial shifting. This δD shifting indicates that groundwater flow patterns develop primarily in shallow aquifers. Deep flow patterns can occur in several springs, characterized by consistent, light δD and large δD-excess (d), including S13 (Sikantong), S14 (Ngelo), S17 (Mudal) springs.

Isotopic enrichment through evaporation occurs during the dry and rainy seasons. This isotopic enrichment is characterized by an increase in δD content and a relatively small d value, such as in S25 (Clapar) springs. During the rainy season, isotopic enrichment can also occur due to mixing with surface water that has undergone evaporation first. This mixing with surface water process is usually characterized by heavy and shifted δD, for example in S1 (Munggangsari) spring. δD enrichment occurs in the rainy season which marks evaporated surface water mixing also occurs in S11 (Pagertengah), S21 (Jatimulyo) and S25 (Clapar) springs.

A big and consistent value of d is found in spring S7 (Anjani) marking thin soil resulting in rapid infiltration. Anjani spring is more evaporated during the dry season, this is related to the warmer temperatures in that season. A big and consistent d value marks a rapid infiltration process, usually occurring in springs with the Jonggrangan Formation aquifer. Examples of these springs include S14 (Ngelo), S20 (Seplawan) springs. However, springs in the Old Andesite Formation can also experience this, for example in S26 (Durensari) spring.

A small value of d marks a high evaporation process, such as S16 (Hulosobo) springs in the rainy season. It shows the enrichment process which is more developed during the rainy season. S25 (Clapar) spring has a small d in all seasons, marking infiltration water that has undergone evapotranspiration before infiltration below the surface.

The interpretation of groundwater flow patterns based on stable isotope content can be made with the following considerations.

1. Based on ^{18}O stable isotope content.

Groundwater isotopic fractionation runs from light to heavy isotopes. Isotopic evolution resulting in an increase in $\delta^{18}O$ strongly supported by an increase in TDS (Listyani, 2016) is also evident in the study area. Therefore, groundwater flow patterns can be interpreted in accordance with the direction of enrichment of iso-^{18}O.

2. Based on the stable isotope content of D.

Although the increase in δD is not followed by TDS, the enrichment of D isotope can be interpreted in line with the flow pattern, so long as the pattern does not conflict with the flow pattern based on $\delta^{18}O$.

3. Groundwater flow patterns are also made by considering the similarity of the range values in each spring compared to nearby springs. The similarity of the range values means that groundwater from springs having overlapping values is groundwater from the same source or the two springs are interconnected.

Synthesis of the groundwater flow system and pattern

The appearance of springs and groundwater flow patterns in the study area is part of the hydrogeological aspects of the study area which is included in the non groundwater basin or less potential groundwater basin. Groundwater can be found locally as wells and dug wells.

The dominance of bicarbonate ions in the groundwater studied shows that groundwater comes from local meteoric water, fresh and relatively young. This condition supports groundwater flow patterns in local/shallow systems. Groundwater flows in a not too long time, which means it has a short residence time. Chebotarev (1955, in Domenico & Schwartz, 1990) states that hydrochemical of groundwater is a reflection of residence time in the aquifer, where interactions can continue to occur until groundwater reach hydrochemical equilibrium. The short stay in the groundwater flow process in the study area is shown in the carbonate facies supported by low TDS content.

Groundwater flow system

The results of this groundwater flow system synthesis concluded that the study area had a local groundwater system. Matters supporting the local groundwater system is explained as follows.

a. Based on hydrochemistry

- The hydrochemical evolution of groundwater has not evolved yet, so it is not clear in changing groundwater facies. All locations in the study area show bicarbonate groundwater facies, which means they are in an early phase of evolution, where groundwater enters and exits in a short time and flows at short distances as well.

- The weak correlation between TDS vs elevation indicates that evolution has not yet developed. In a basin, groundwater at low elevation generally will be more evolved (Ako *et al.*, 2012), but groundwater in the study area does not show a clear change in groundwater ion / TDS content to elevation.

b. Based on hydroisotopes

- Based on the stable isotope content it is known that groundwater comes from local precipitation and has not undergone significant isotopic evolution. This is indicated by an increase in groundwater isotope content which is not followed by an increase in TDS as well as spring elevation.

- The variation of $\delta^{18}O$ in the dry season is 1.89, while δD is 11.9 ‰ and increased to 3.43 ‰ for $\delta^{18}O$ and 21.9‰ for D. This significant variation of stable isotope content shows that the residence time is relatively short and the catchment area is not too far away (Satrio & Sidauruk, 2015).

This synthesis is also supported by the results of previous studies that revealed that groundwater generally develops in shallow aquifers (Budiadi *et al.*, 2017) and local systems (Isnawan *et al.*, 2017). The characteristics of shallow groundwater in the rainy season mostly tend to be near the meteoric line (Satrio *et al.*, 2017).

Groundwater flow pattern

Groundwater flows through a fresh or half-weathered - weathered rock aquifer system into a colluvium deposit. The groundwater aquifers are mainly rocks from the Jonggrangan and Old Andesite Formations. Groundwater flowing on the Jonggrangan Formation rocks is generally controlled by porosity between grains, cracks, and channels due to the dissolution of carbonate minerals. Meanwhile, groundwater in the Old Andesite Formation is usually controlled by crack / joint porosity. The weathering process greatly helps the groundwater flow process in the groundwater flow system, so that the flow pattern develops in rocks that are starting to decay / half weathered.

The process of groundwater flow in the local system takes place at a short distance and a relatively short time. Local groundwater flows at short distances, enter the ground and exit through springs or wells. Infiltration can occur in the spring/well or in the surrounding area not far from the spring / well. However, groundwater flow patterns also develop in relatively fresh rocks, especially in the Jonggrangan Formation carbonate rock. In this case, groundwater flow maybe takes a longer trip if dissolving limestone channels or underground rivers are interconnected.

Based on a compilation of geological (Listyani *et al.*, 2018, 2019), hydrochemical and stable isotope analysis, groundwater flow patterns can be made as follows (Figures 7 - 8). The groundwater flow map was done by data of grondwater table measured from dug wells, compiled with hydrochemical and isotopes analysis. The significant difference in groundwater flow occurs in deep flow between two seasons especially in the center of research area. There is a deep groundwater flow from Seplawan (S20) to Mudal (S17) and continues toward Sikantong (S13) in rainy season. However, the deep groundwater is only interpreted beetween Jatimulyo (S21) to Seplawan.

a. The shallow groundwater flow pattern is in accordance with the local topography (Listyani, 2019).

- The flow pattern develops from the Ca-HCO_3 facies, then goes to Ca, Mg-HCO_3 then Mg-HCO_3 and finishes at the Ca, Na-HCO_3 facies.

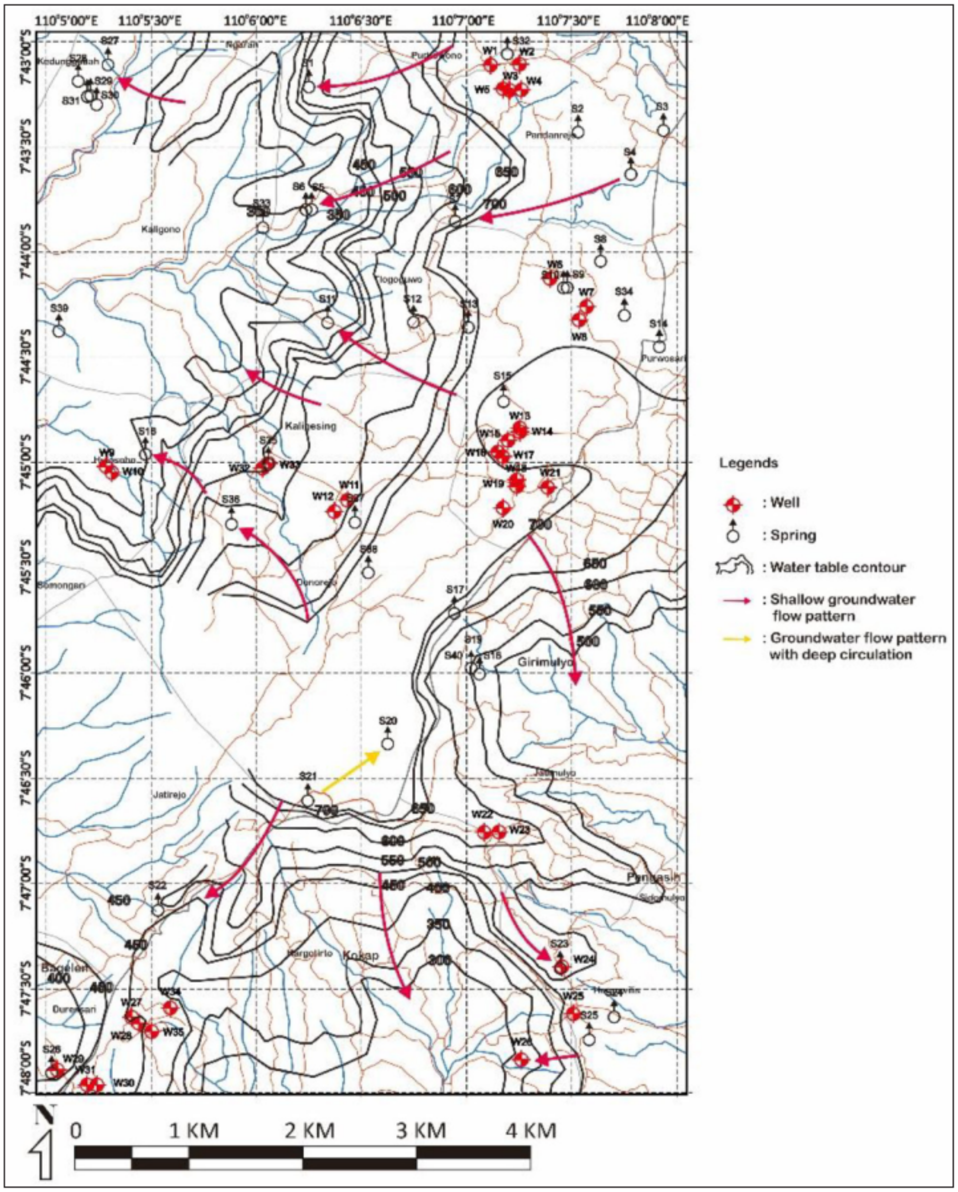

Figure 7: Resume of groundwater flow pattern interpretation in the dry season.

- Groundwater flow patterns are supported by enrichment of the ^{18}O and D. isotopes. If the direction of enrichment of the two isotopes is contradictory, then the enrichment of the ^{18}O isotope is preferred.
- In the Jonggrangan Formation it is possible to have deep groundwater flow patterns through conduit porosity which can be interpreted based on isotope analysis, but still consider hydrochemical evolution. This deep groundwater flow pattern does not follow the local surface relief.
- In the Old Andesite Formation, isotope analysis support can produce shallow groundwater flow patterns.

Conformity of shallow groundwater flow with topography also applies to other areas in its vicinity (Listyani *et al.*, 2017; Listyani & Budiadi, 2018).

b. Groundwater flow patterns with deep circulation, indicated by:

- Hydrochemical groundwater with bicarbonate facies.
- Isotope content is stable with consistent, light δD and big d.

For more details, the conceptual model of groundwater flow is briefly illustrated by the 3D block diagram in Figure 9 and the cross-section in Figure 10. The figure shows the pattern of groundwater flow in the West Progo Dome

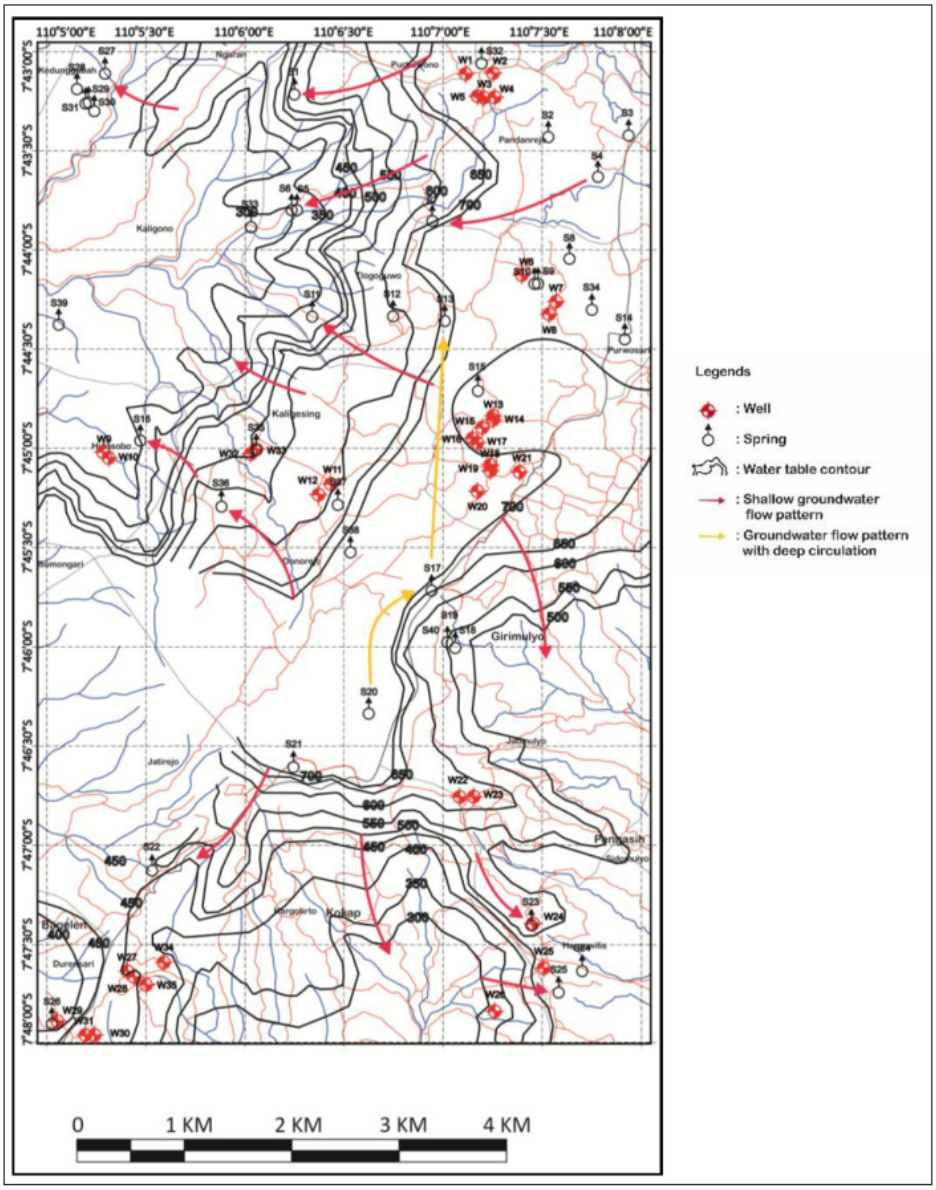

Figure 8: Resume of groundwater flow pattern interpretation in the rainy season.

area that flows locally with almost the same variation in the dominant type of bicarbonate and light to heavy stable isotopic variations. Groundwater flow with deep circulation can be formed in the study area through the limestone cavities of the Jonggrangan Formation. The shallow groundwater flow may occur in many places to a depth of 20 m.

CONCLUSIONS

Analysis of the hydrochemical and stable isotopes characteristics of groundwater in the central West Progo dome area resulted in findings of local groundwater flow systems and patterns. Hydrochemical characteristics in the study area show that groundwater has bicarbonate facies, neutral pH, low TDS, and EC. Hydrochemical processes include leaching, dissolution, ion exchange and sulfate reduction, but groundwater evolution has not developed yet.

Hydrochemical facies of groundwater is influenced by rock material due to water-rock interactions. Seasonal changes trigger hydrochemical characteristics changes. Meanwhile, the groundwater isotopes characteristics in the study area indicate that groundwater is supplied by rainwater with light to heavy isotopes contents. The isotopic evolution of groundwater is not yet clear. Changes in isotope content due to seasonal changes. Finally, the synthesis of

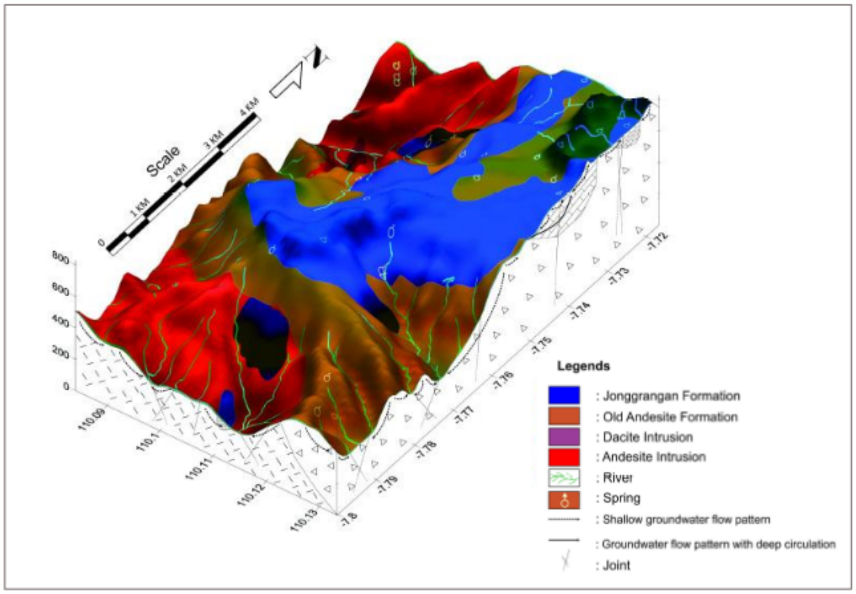

Figure 9: The 3D block diagram of groundwater model in the research area.

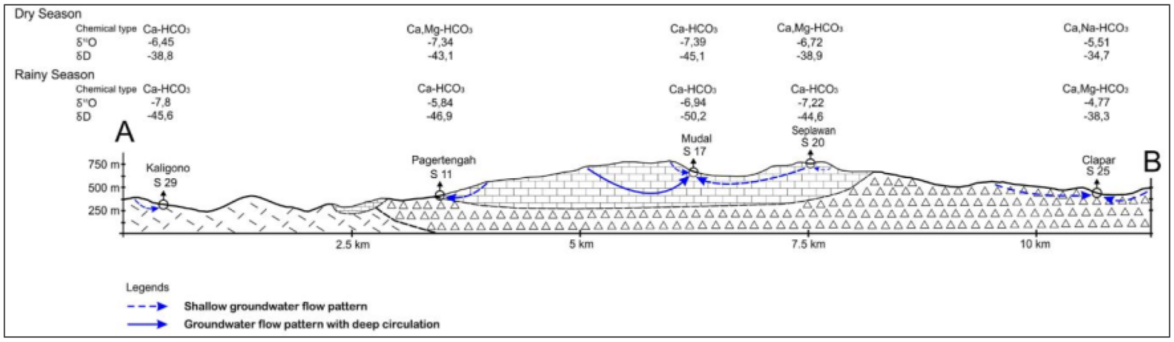

Figure 10: Hydrochemical and hydroisotopes cross-section.

groundwater flow systems in the study area results that the groundwater flows in the local system. The groundwater flow can be divided into two patterns types namely shallow and deep groundwater flow patterns, where deep groundwater flow patterns may develop in the Jonggrangan Formation aquifer.

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