INSTITUT TEKNOLOGI NASIONAL YOGYAKARTA
Technopreneur In Future Energy

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submission full paper

Listiani RA <lis@itny.ac.id> 20 Juni 2020 18.43
Kepada: icenis@live.undip.ac.id

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Chemical Type Variation of Groundwater in Borobudur and Surroundings Area, Magelang District

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Abstract. Hydrogeological surveys have been carried out in the Borobudur area and its surroundings, the northern part of the West Progo Hills to the Magelang intermountain plains. The purpose of this study is to determine the variations in groundwater's chemical types in the study area and to interpret the hydrochemical processes. Primary data was taken in the field, including groundwater data and rock petrology. Physical / chemical data of groundwater were obtained from laboratory test results. Data analysis includes hydrochemical analysis using the Stiff, Piper, and Durov diagrams. The result shows that groundwater in the study area has a wide variety of chemical types, namely Ca, Mg - bicarbonate; Ca, Mg, alkaline – bicarbonate; Alkaline, Ca – chloride, and Alkaline - chloride. Groundwater in the study area is fresh (type Va) to brackish (type Vc), with low - moderate TDS content (119 - 6,810 ppm), and soft calcium carbonate hardness (6.0 - 16.6 ppm). Hydrochemical processes occur in groundwater are simple dissolution and cation exchange caused by clay materials originating from Quaternary deposits or weathering of Old Andesite Formation volcanic breccia. In addition, the presence of brackish water in Karangrejo and Candirejo may be triggered by mixing with fossil water.

1 Introduction

The research area is located in Borobudur and its surroundings, Magelang Regency (Fig. 1), which is included in the southern part of the Mungkid sheet map. Geographically, the study area is included in the coordinates 110^{o}7'15 "- 110^{o}13'45" South Latitude and 7^{o}35'45 "- 7^{o}37'40" East Longitude.

The northern research area is included in the physiography of the Java central depression or intra mountain of the Quaternary volcano, while the southern part is included in the West Progo Hills [1]. West Progo Hills physiography is a non-groundwater basin region [2]. In this area, groundwater can be found with varying quantity and quality.

In quantity, groundwater is generally quite abundant in alluvial / coluvial deposits, and only a few can be extracted from hard rock. Meanwhile, groundwater quality also shows variations from fresh to brackish. This varying quality of groundwater is characterized by different types of groundwater chemistry.

Determination of the type of groundwater chemistry becomes important in hydrogeological studies. By knowing the type of groundwater chemistry, we can also provide recommendations for groundwater quality that are suitable for the local community's purpose. Good groundwater quality will have a certain type of groundwater

chemistry, with certain major elemental content, according to the limits recommended by the government.

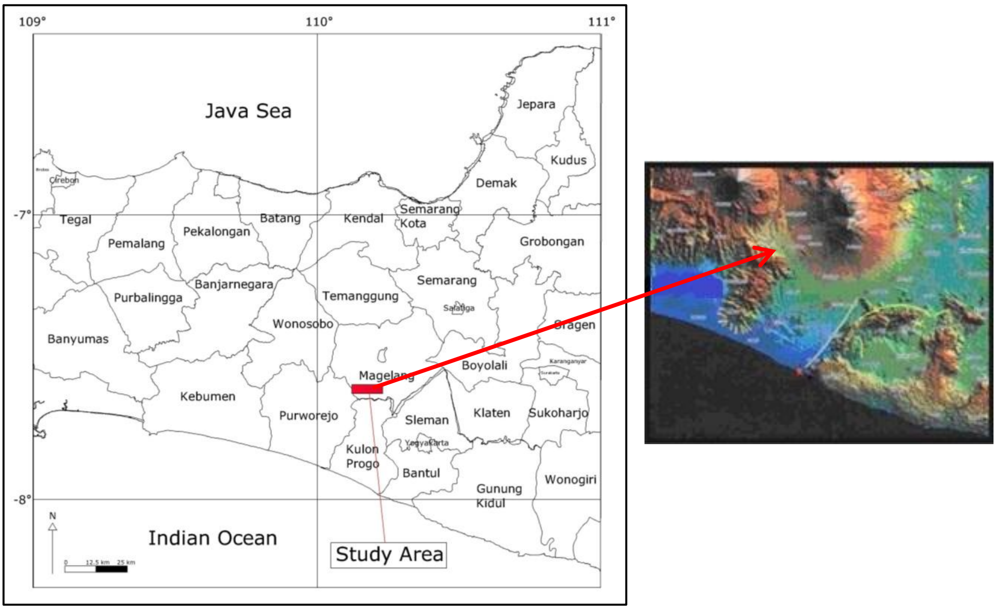

Fig. 1. Research area in Borobudur and its vicinity, Central Java

2 Method

Hydrogeological surveys in the field are conducted to determine the condition of groundwater resources in the study area. This survey was conducted to retrieve the geological data of the study area to obtain an overview of the geological characteristics and groundwater potential. Groundwater sampling was carried out at springs and dug well at four locations. Selected springs are moderate or large discharge springs.

Physical / chemical of groundwater laboratory tests were carried out at BBTKLP Yogyakarta Laboratory. Meanwhile, petrological data were obtained directly in the field as well as laboratory descriptions of rock samples. The primary data then analyzed to determine variations in the type of groundwater chemistry and the interpretation of hydrogeological processes using the Stiff, Piper and Durov diagrams.

3 Regional Geology of Research Area

The research area is located in Borobudur and its surroundings, Magelang Regency (Fig. 1), which is included in the southern part of the Mungkid sheet map. Geographically, the study area is included in the coordinates 110^{o}7'15 "- 110^{o}13'45" South Latitude and 7^{o}35'45 "- 7^{o}37'40" East Longitude.

The hydrogeological conditions in the Menoreh Hills have low groundwater potential. The steep slope causes rain water that is received by the land surface to gather in river channels and flow downstream rapidly. In this condition, rainwater is not infiltrated into the soil in sufficient quantities. On the other hand, the geology of the research area on the West Progo Hills physiography is dominated by materials in the form of Old Andesite Formation (OAF) andesite breccias, tuffs, lapilli tuffs, agglomerates, and intercalation of andesite lava flows and Nanggulan sedimentary rocks (sandstones, claystone). The OAF rocks were formed by ancient volcanic activity in the Tertiary and impermeable. As a result, these materials are not able to store and drain water so groundwater reserves in this region are very minimal. Groundwater in this region is often found in rock fractures [3]. Meanwhile, the northern part of the study area is included in the central depressive zone which is partly located south of Borobudur Hill. This hill was part of the West Progo Dome which was broken and then sank at the end of the Tertiary Age [1]. Around the broken part, young volcanoes grew in the Quaternary Period, namely Sumbing, Merapi and Merbabu. The broken part eventually becomes the intermountainous basin and forms the ancient lake of Borobudur. These ancient lake deposits are characterized by the presence of black clay deposits [4].

4 Research Data

4.1 Field Data

Observation location data and lithology are presented in Table 1. Some examples of springs and dug wells examined are shown in Fig. 2.

Table 1. Location of research observations in Borobudur and surrounding areas.

Loc.	Coordinate		Area	pH	TDS	Litology
	Longitude	Latitude				
S1A	110° 11’ 13”	-7° 37’ 09”	Karanganyar	7.4	42	Quaternary sediment
S1B	110° 10’ 56”	-7° 37’ 09”	Karanganyar	5.5	44	Nanggulan sandstone
R2	110° 10’ 28”	-7° 37’ 25”	Badrawati	9.6	31	Quaternary sediment
W3	110° 10’ 05”	-7° 37’ 36”	Giri Tengah	10.7	41	Quaternary sediment
R4	110° 09’ 27”	-7° 36’ 48”	Giri Tengah	10.8	40	Quaternary sediment
W5	110° 10’ 28”	-7° 36’ 52”	Ngadiharjo	5.4	94	Quaternary sediment
S6	110° 10’ 46”	-7° 36’ 37”	Karanganyar	8.6	37	Quaternary sediment
W7	110° 10’ 38”	-7° 36’ 17”	Karangrejo	5	1326	Quaternary sediment
W8	110° 09’ 49”	-7° 35’ 48”	Kembanglimus	4.6	134	Quaternary sediment
S9	110° 09’ 52”	-7° 36’ 14”	Kembanglimus	6.4	27	Quaternary sediment
W10	110° 10’ 11”	-7° 36’ 15”	Tawangsari	6.1	49	Quaternary sediment
W11	110° 09’ 48”	-7° 37’ 33”	Karangrejo	6.6	39	Nanggulan sandstone

Table 1. (Continued)

S12	110° 10’ 14”	-7° 36’ 37”	Giri Tengah	12.6	19	Quaternary sediment
W13	110° 09’ 48”	-7° 36’ 45”	Karanganyar	7.6	99	Quaternary sediment
S14	110° 09’ 27”	-7° 37’ 11”	Ngadiharjo	5.2	93	Quaternary sediment
W15	110° 09’ 62”	-7° 37’ 26”	Ngadiharjo	4.5	79	Quaternary sediment
W16	110° 09’ 04”	-7° 36’ 51”	Giri Tengah	5.1	72	Quaternary sediment
W17	110° 08’ 48”	-7° 36’ 07”	Ngadiharjo	5.8	76	Quaternary sediment
W18	110° 08’ 48”	-7° 35’ 49”	Paripurna	5.3	56	Quaternary sediment
W19	110° 08’ 30”	-7° 36’ 56”	Paripurna	5.9	61	Andesite breccia OAF
R20	110° 08’ 22”	-7° 37’ 07”	Paripurna	5.4	48	Quaternary sediment
S21	110° 08’ 07”	-7° 36’ 52”	Paripurna	5.5	14	Quaternary sediment
S22	110° 07’ 25”	-7° 36’ 56”	Paripurna	5.2	17	Quaternary sediment
S23	110° 07’ 34”	-7° 36’ 16”	Paripurna	4.9	23	Quaternary sediment
R24	110° 08’ 25”	-7° 36’ 20”	Paripurna	5.1	15	Andesite of OAF
R25	110° 13’ 27”	-7° 37’ 35”	Paripurna	4.9	49	Nanggulan claystone
S26	110° 13’ 33”	-7° 37’ 32”	Candirejo	6,8	1430	Andesite breccia of OAF
W27	110° 13’ 22”	-7° 36’ 50”	Candirejo	6.5	165	Quaternary sediment
W28	110° 08’ 33”	-7° 37’ 01”	Candirejo	6.7	54	Quaternary sediment
W29	110° 11’ 06”	-7° 36’ 26”	Paripurna	7.4	42	Nanggulan Sandstone

Note: S: spring; W: well; R: river

Groundwater found at the S1A location (Fig. 1a) appears on the sediment, is rather turbid, brownish in color, but tasteless and odorless. Groundwater pH value is 7.4, while TDS is 42 ppm. The spring in Paripurno Village (Fig. 1b) shows dolorless, clear, with a relatively acidic pH (5.5) and a low TDS (17 ppm). Different condition occurs in Candirejo spring (S26) where the groundwater shows brown, turbid, odorless but rather salty, pH 6.8 and TDS measured in the field at 1430 ppm.

Groundwater from dug wells found in Karangrejo (W7) and Kembanglimus (W8) shows colorless, clear and odorless characteristics. Groundwater in W7 tastes a bit salty, but groundwater in W8 does not taste. The measured pH in groundwater at W7 and W8 is 5 and 4.6, while the TDS is measured at 1326 and 134 ppm. The two wells tapped water from Quaternary deposits, but differed in salinity. The presence of brackish groundwater is localized. [5] mentioned that the distribution of groundwater quality in a place is not always easy to model, even the presence of brackish water is not always related to morphology.

Fig. 2. Springs found at (clockwise): a. Karanganyar Village (S1A); b. Paripurno (S22); c. Karangrejo (W7); and d. Kembanglimus (W8).

4.2 Laboratory Data

The laboratory test results of physical / chemical of groundwater are presented in Table 2. Physically, groundwater in the study area is generally tasteless to brackish, and odorless. Groundwater pH values tend to vary from normal to acidic. The groundwater studied was clear to turbid, with TDS varying from small to large enough.

The types of groundwater chemistry studied were highly variable (Table 2), namely Ca, Mg bicarbonate; Ca, Mg, alkaline - bicarbonate; alkaline, Ca - chloride and alkaline - chloride. The dominant major cations composing groundwater vary greatly, while the major anions are dominated by bicarbonate and chloride ions.

Table 2 also shows that the groundwater samples had greatly varied TDS from 119 to 6810 ppm. According to Caroll's classification (1962, in [6]) the groundwater is fresh to brackish water.

Meanwhile, the carbonate hardness of the groundwater was 6 - 16.57 ppm or <75 ppm. According to the Sawyer & Mc. Carty (1967, in [6]), it is soft groundwater. This means that there are not enough carbonate ion sources in the study area. The carbonate rocks in which groundwater passes through are only a thin layer of carbonate sandstone or claystone of the Nanggulan Formation.

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Table 2. Physical / chemical data of groundwater test results in the laboratory.

No	Parameter	Sample			
		S1A	**S1B**	**W7**	**S26**
1	Ca^{2+} (ppm)	20.1	21.71	107.74	45.02
2	Na^{+} (ppm)	20	21	503	2294
3	K^{+} (ppm)	3	3	12	82
4	Mg^{2+} (ppm)	11.23	9.77	9.28	23.93
5	Cl^{-} (ppm)	8.5	13	1742.5	4198.7
6	HCO_3^{-} (ppm)	108.2	96.2	276.4	156.3
7	SO_4^{2-} (ppm)	6	1	88	1
8	TDS (ppm)	119	129	2840	6810
		fresh	fresh	brackish	brackish
9	pH	5.7	5.5	6.5	6.4
10	Hardness	6.30	6.00	16.57	13.69
		soft	soft	soft	soft
11	Chemical type	Ca,Mg - bicarbonate	Ca, Mg, alkaline - bicarbonate	Alkaline, Ca - chloride	Alkaline-chloride

Meanwhile, the carbonate hardness of the groundwater was 6 - 16.57 ppm or <75 ppm. According to the Sawyer & Mc. Carty (1967, in [6]), it is soft groundwater. This means that there are not enough carbonate ion sources in the study area. The carbonate rocks in which groundwater passes through are only a thin layer of carbonate sandstone or claystone of the Nanggulan Formation.

4 Hydrochemical of Groundwater

4.1 Stiff diagram Analysis

The study of water chemistry begins with looking at the chemical content of major ions in groundwater. The following Table2 are resumes of chemical elements / compounds, pH, TDS, hardness, and types of groundwater chemistry. The type of groundwater chemistry turned out to have wide variations. Considerable differences in the content of chemical elements can also be seen clearly on the Stiff diagram (Figure 3).

The dominance of the bicarbonate anion shows that groundwater in several places in the study area is generally new groundwater, which comes from precipitation in recharge area. This groundwater comes from rainwater that falls in the local area, so it has a relatively young age. However, a large alkali content indicates that there is already a process of enrichment of these elements through a hydrochemical process.

Brackish groundwater is interpreted as groundwater that has undergone evolution or enrichment in salinity. This can occur through the process of ion exchange due to the interaction / prolonged contact between groundwater to the rocks in its path [5].

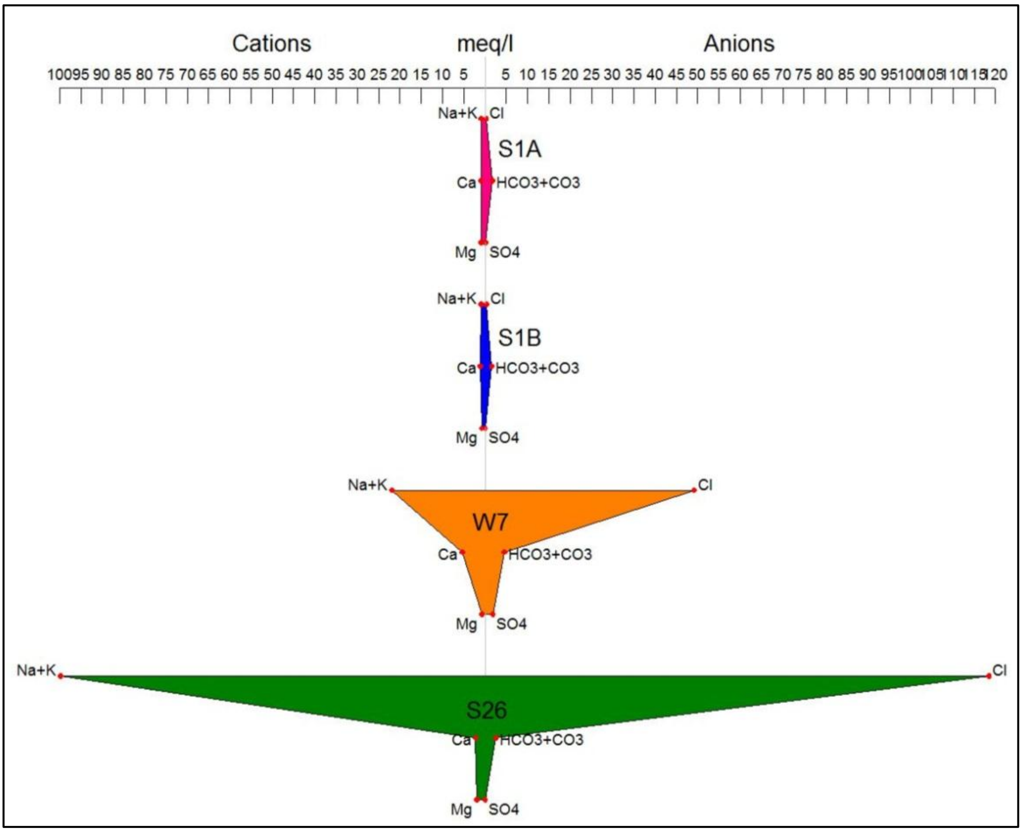

Fig. 3. Stiff diagram of groundwater samples.

4.2 Trilinier Piper Diagram Analysis

This analysis method is important for groundwater genetic studies and geochemical problems [7]. The interpretation of groundwater quality types can be determined by observing the dominant group of data plotting results in the parallelogram of Piper diagram. The chemical plots of major elements contained in the groundwater are presented in Figure 4.

According to the Piper diagram, groundwater from springs in Karanganyar is included in 1, 3, 5 classes (Table 2), while groundwater that is found in W7 dug well (Karangrejo) and spring in W26 (Candirejo) are included in type 2, 4, and 7 water classes. From the diagram it appears that groundwater in Karanganyar is freshwater with a few mixing process. This is supported by the relatively low TDS value, which is around 119 - 129 ppm according to Carroll (1962, in [6]). The dominant processes occurring in groundwater in Karanganyar are leaching and mixing.

The groundwater from Karangrejo well and Candirejo spring is almost saline according to the Piper diagram or brackish groundwater refers to Carroll classification (1962, in [6]) with TDS 2840 and 6810 ppm. Both types of groundwater are the result of the mixing process or fossil water, but they are far from sea water intrusion process (Figure 4).

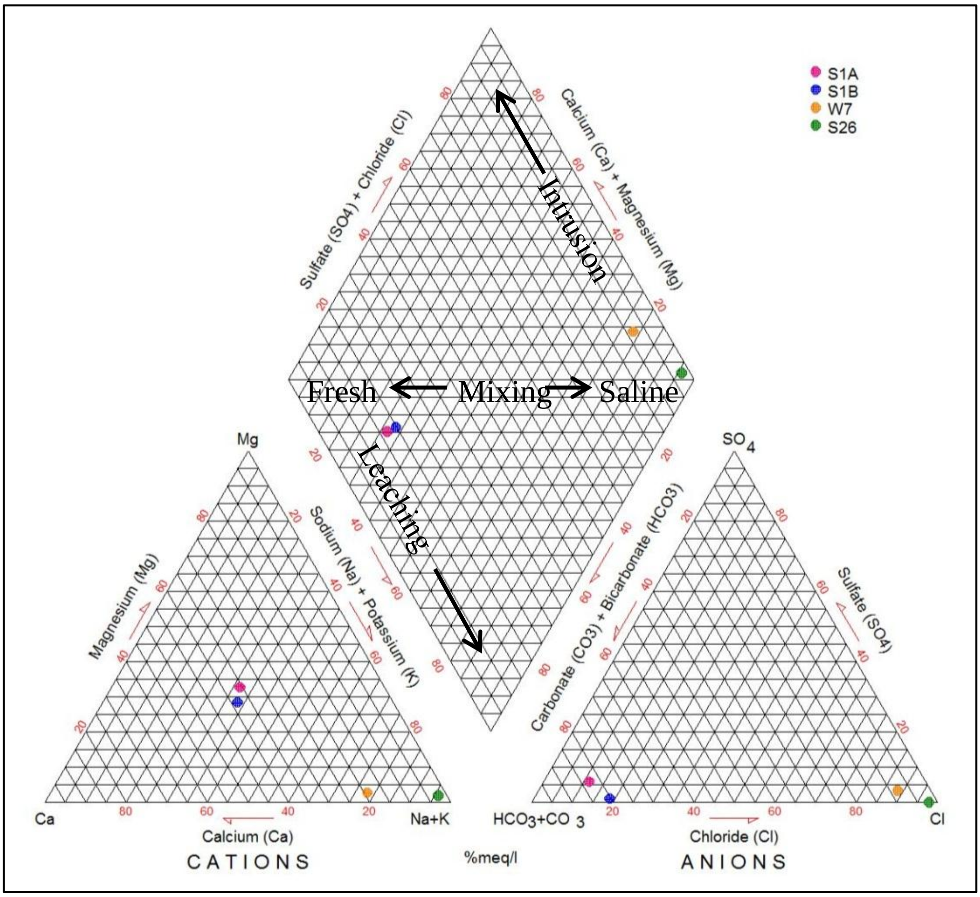

Fig. 4. Plot data of groundwater in Piper diagram.

Table 2. Types of groundwater chemistry in the study area.

Location		**Type**		**Facies**	
No	**Village**	**Cations**	**Anions**		
S1A S1B	Karanganyar	D type (No dominant type)	E type (Bicarbonate type)	1	Alkaline earths ($Ca^{2+} + Mg^{2+}$) exceed alkaline ($Na^{+} + K^{+}$).
				3	Weak acids ($CO_3^{2-} + HCO^{-}_3$) exceed strong acids ($SO_4^{2-} + Cl^{-}$).
				5	Magnesium bicarbonate type with carbonate hardness (secondary alkalinity) > 50%, groundwater is dominated by alkaline soils (Ca^{2+} + Mg^{2+}) and weak acids (CO_3^{2-} + HCO_3^{-}).

Table 2. (Continued)

W7 S26	Karangrejo Candirejo	C type (Sodium & potassium / Alkaline type)	G type (Chloride type)	2	Alkali ($Na^+ + K^+$) exceeds the alkaline earth ($Ca^{2+} + Mg^{2+}$).
				4	Strong acids (SO_4^{2-} + Cl^-) exceed weak acids ($CO_3^{2-} + HCO_3^-$).
				7	Sodium chloride type with non-carbonate alkali (primary salinity) > 50%, the chemical properties of groundwater are predominantly alkaline ($Na^+ + K^+$) and strong acids ($SO_4^{2-} + Cl^-$).

4.3 Piper Quadrangle Diagram Analysis

Piper's trilinier method has been developed into a quadrangle system [8] (Fig. 5), by dividing groundwater hydrochemicals into 6 hydrochemical types. According to this Piper rectangular diagram, groundwater is included in class V (fossil / connate water). Groundwater in Karanganyar is included in type Va, while groundwater in Karangrejo and Candirejo is included in type Vc.

According to Piper's quadrilateral diagram, the S1A and S1B groundwater samples from Karanganyar springs are included in the fossil water type, but are still close to group I (bicarbonate water). Groundwater is included in the Va type, although including bicarbonate facies, but this groundwater contains a fairly large alkaline elements. The presence of a large enough alkali can be sourced from feldspar minerals, clay minerals or rock fragments (Bowen, 1986 in [9]). Feldspar minerals are easily weathered silicate minerals, according to Goldich sequence weathering (Goldich, 1938, in [10]).

Although dominated by bicarbonate ions, groundwater in Karanganyar is not solely supplied by rainwater, but there is a cation exchange process that accompanies it. This condition is very likely to occur, because the local aquifer is clayey Quaternary sediments. These sediments are generally part of ancient lake sediments [4]. The tendency of groundwater to be of type Va is much controlled by the cation exchange process. The ion exchange processes in groundwater particularly occur in clay minerals [11]. The high salinity in the groundwater can also be supported by the existence of a deaquation process (Drever, 1988 in [12]). Some salt / brackish water events can also occur due to salt concentration through the process of salt sieving in fine-grained sediments [13].

4.4 Durov Diagram Analysis

The Durov diagram is almost similar to the Piper diagram because it also uses a trilinier diagram. In this diagram we can see the existence of a hydrochemical process that mainly occurs in the study area (Fig. 6).

The groundwater sample plot from the Karanganyar spring enters area 2 in the diagram which means that the groundwater has the dominant characteristics of HCO_3^-, Ca^{2+} and Mg^{2+} which are quite large, associated with certain minerals. Ca^{2+} and Na^+ are an important part of the ion exchange process [13]. In addition to ion exchange, groundwater in the Karanganyar area undergoes a simple dissolution or mixing process.

The groundwater samples from the Karangrejo well and Candirejo springs enter area 9, which means that the groundwater is the result of an advanced process of simple dissolution or mixing. This area shows that Cl^- and Na^+ are dominant and often mark end-point waters.

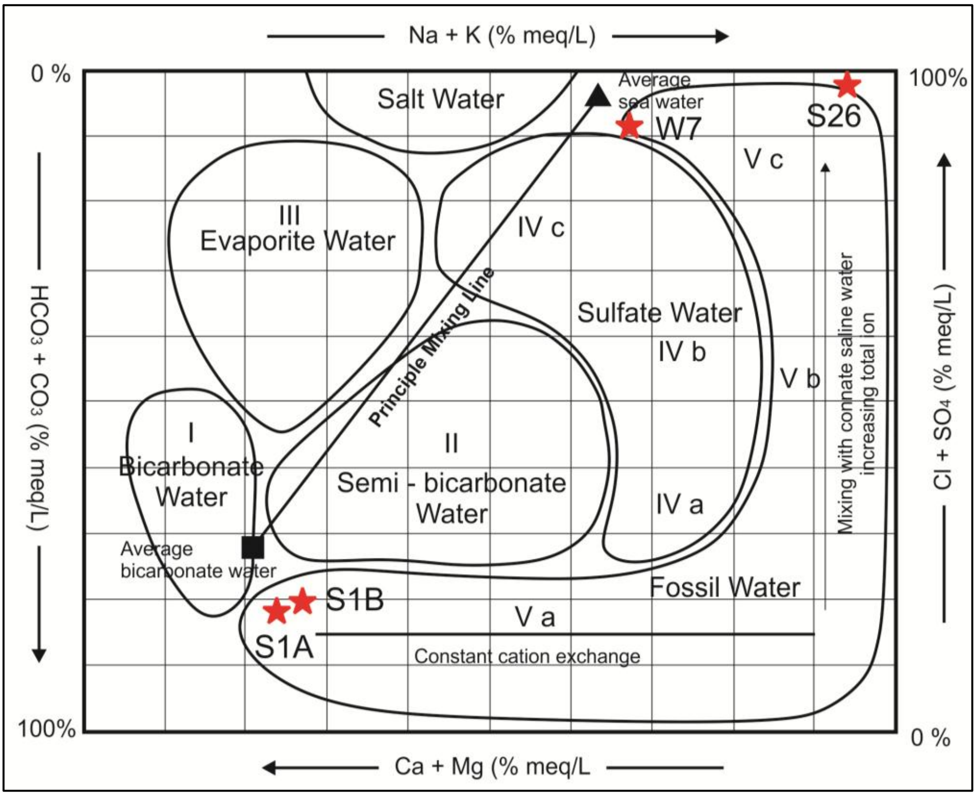

Fig. 5. The hydrochemical type of groundwater on a rectangular Piper diagram.

The Durov diagram shows that the ion exchange process is an important process in freshwater in the study area. This might happen to Quaternary volcanic rocks or sediments which contain a lot of clay minerals. Porous geological material composed of a number of colloidal sized particles such as clay minerals has the ability to exchange ions that are absorbed on the particle surface. Clay minerals generally exhibit surface charges due to ion substitution [14]. The tendency of ion adsorption depends on the pH of the solution. Variations in the number and types of ions will reflect the composition of ions in the clayey sediments.

The simple dissolution or mixing process shown in brackish groundwater at Karangrejo and Candirejo is supported by clay material derived from Quaternary sediments or weathered volcanic breccia of the Old Andesite Formation. The process can take a long time so that the evolution of anions tend to be the hydrochemical type of sea water.

Rocks in the study area can function as aquifers. The results of weathered aquifer and non-aquifer rocks can produce clay material that supports the ion exchange process. The aquifer found in Karanganyar shows the size of sand grains with high porosity and permeability, supported by intergrain pores. Many springs in the study area are supported by Quaternary aquifer like this conditions. In addition to Quaternary deposits, compact rocks such as OAF andesite breccias and Nanggulan sandstones can also function as aquifers.

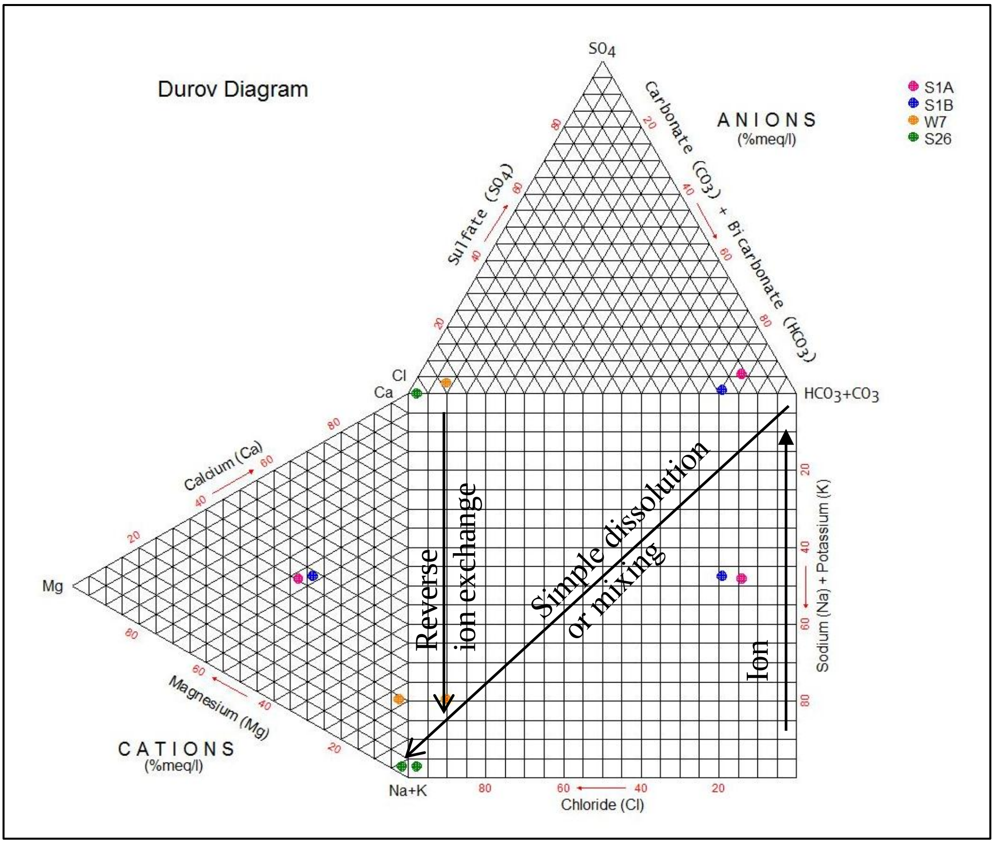

Fig. 6. Plot of groundwater data in Durov diagram (Lloyd & Heathcote, 1985).

Based on several analyzes before, it appears that groundwater in the study area has a wide variation in chemical types. This is influenced by the varying hydrochemical processes as groundwater travel below the surface.The existence of fresh groundwater is usually associated with local precipitation where rainfall still dominates the type of groundwater chemistry. Groundwater in Karanganyar with bicarbonate facies is young groundwater but there is already an influence on the process of alkaline ion enrichment of soluble mineral feldspar through long water-rock interaction.

Meanwhile, brackish water can be caused by ion exchange processes in Quaternary clay deposits or claystone that can affect groundwater quality through water-rock interaction process. This is supported by the presence of Nanggulan claystone around the Candirejo spring. The process of ion exchange between groundwater and rocks in its path is very easy to occur in clay minerals [12].

The presence of alkali ions (Na, K) is quite dominant in groundwater is usually comes from the weathering of silicate rocks [10]. Furthermore, Grim (1953, in Listyani, 2016a) says that the weathering process is an example of an ion exchange process that involves the release of alkali or alkaline earth ions. It may be mainly controlled by weathering and balance of evaporation-precipitation conditions [15]. Feldspar is an influential source of alkaline ions [12]. A longer period of water-rock reaction can occur as long as groundwater flows below the surface and results in the enrichment of ions in it.

5 Summary

Groundwater in the study area has a cation element that varies from one place to another, with the dominant anion of bicarbonate or chloride. The types of groundwater chemistry in the study area varied greatly including Ca, Mg - bicarbonate; Ca, Mg, alkaline - bicarbonate; alkaline, Ca-chloride and alkaline chloride.

Groundwater salinity in the study area varies from fresh to brackish. The chemical content of the goundwater in Karanganyar is supported by low TDS, freshwater with type Va. The dominance of bicarbonate ions shows that this groundwater is much influenced by precipitation, but there are already indications of mixing or ion exchange processes. This groundwater is young which is affected by the process of long enough water - rocks interaction or soluble minerals. The physical / chemical character of groundwater is influenced by the presence of Old Andesite and Nanggulan Formation rocks as well as clay deposits which support the cation exchange process.

Brackish groundwater is also found in the Vc type in research areas, especially in Karangrejo and Candirejo. This groundwater has a large TDS, but is still soft. The groundwater is the result of simple dissolution or mixing processes in the advanced phase. The process of ion exchange and mixing with fossil water is also possible in this area. The ion exchange process develops because of the large amount of clay content in Quaternary deposits.

Acknowledgment

This paper is based on the results of research in 2016 by funding of Kopertis V Yogyakarta, therefore the authors would like to thank for the support of Kopertis V and STTNAS Yogyakarta so that this paper can be completed.

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Chemical Type Variation of Groundwater in Borobudur and Surroundings Area, Magelang District

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Presentation at 5th ICENIS 2020

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Semarang, July 28st 2020

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International Conference on Energy, Environment, Epidemiology and Information System

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Full paper revision ENV.4-012 T. Listyani R.A.

Listiani RA <lis@itny.ac.id> 11 Agustus 2020 20.32
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Chemical Type Variation of Groundwater in Borobudur and Surroundings Area, Magelang District

T. Listyani R.A. [1]* and *Sri.Ning* Peni[1]

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Abstract. Hydrogeological surveys have been carried out in the Borobudur area and its surroundings, the northern part of the West Progo Hills to the Magelang intermountain plains. The purpose of this study is to determine the variations in groundwater's chemical types in the study area and to interpret the hydrochemical processes. Primary data was taken in the field, including groundwater data and rock petrology. Physical / chemical data of groundwater were obtained from laboratory test results. Data analysis includes hydrochemical analysis using the Stiff, Piper, and Durov diagrams. The result shows that groundwater in the study area has a wide variety of chemical types, namely Ca, Mg - bicarbonate; Ca, Mg, alkaline – bicarbonate; Alkaline, Ca – chloride, and Alkaline - chloride. Groundwater in the study area is fresh (type Va) to brackish (type Vc), with low - moderate TDS content (119 - 6,810 ppm), and soft calcium carbonate hardness (6.0 - 16.6 ppm). Hydrochemical processes occur in groundwater are simple dissolution and cation exchange caused by clay materials originating from Quaternary deposits or weathering of Old Andesite Formation volcanic breccia. In addition, the presence of brackish water in Karangrejo and Candirejo may be triggered by mixing with fossil water.

1 Introduction

The research area is located in Borobudur and its surroundings, Magelang Regency (Fig. 1), which is included in the southern part of the Mungkid sheet map. Geographically, the study area is included in the coordinates $110^o7'15$ "- $110^o13'45$" South Latitude and $7^o35'45$ "- $7^o37'40$" East Longitude.

The northern research area is included in the physiography of the Java central depression or intra mountain of the Quaternary volcano, while the southern part is included in the West Progo Hills [1]. West Progo Hills physiography is a non-groundwater basin region [2]. In this area, groundwater can be found with varying quantity and quality.

In quantity, groundwater is generally quite abundant in alluvial / coluvial deposits, and only a few can be extracted from hard rock. Meanwhile, groundwater quality also shows variations from fresh to brackish. This varying quality of groundwater is characterized by different types of groundwater chemistry.

Determination of the type of groundwater chemistry becomes important in hydrogeological studies. By knowing the type of groundwater chemistry, we can also provide recommendations for groundwater quality that are suitable for the local community's purpose. Good groundwater quality will have a certain type of groundwater

chemistry, with certain major elemental content, according to the limits recommended by the government.

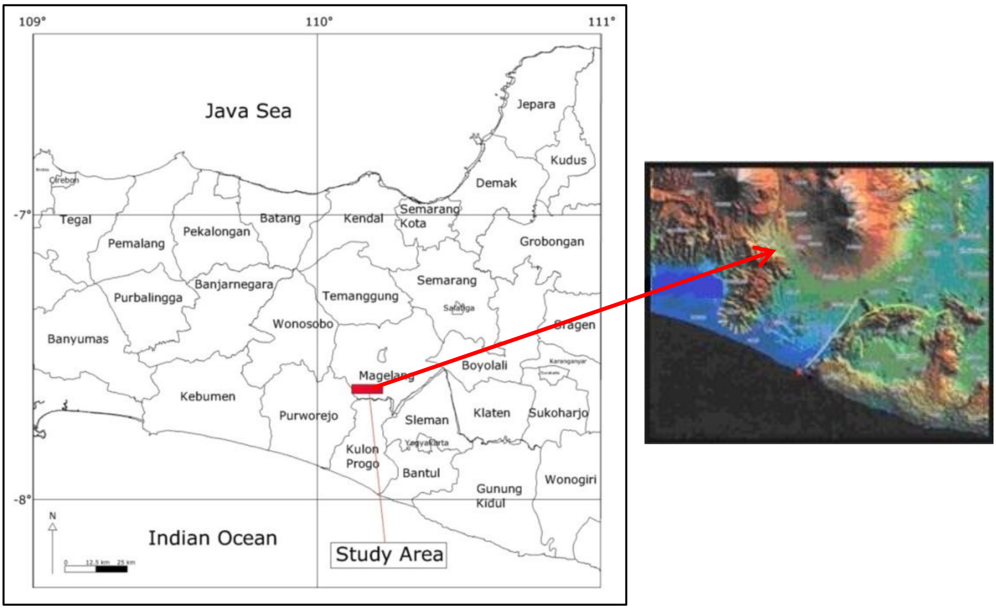

Fig. 1. Research area in Borobudur and its vicinity, Central Java

2 Method

Hydrogeological surveys in the field are conducted to determine the condition of groundwater resources in the study area. This survey was conducted to retrieve the geological data of the study area to obtain an overview of the geological characteristics and groundwater potential. Groundwater sampling was carried out at springs and dug well at four locations. Selected springs are moderate or large discharge springs.

Physical / chemical of groundwater laboratory tests were carried out at BBTKLP Yogyakarta Laboratory. Meanwhile, petrological data were obtained directly in the field as well as laboratory descriptions of rock samples. The primary data then analyzed to determine variations in the type of groundwater chemistry and the interpretation of hydrogeological processes using the Stiff, Piper and Durov diagrams.

3 Regional Geology of Research Area

The geology of the research area on the West Progo Hills physiography is dominated by materials in the form of Old Andesite Formation (OAF) andesite breccias, tuffs, lapilli tuffs, agglomerates, and intercalation of andesite lava flows and Nanggulan sedimentary rocks (sandstones, claystone). The OAF rocks were formed by ancient volcanic activity in the Tertiary and impermeable. As a result, these materials are not able to store and drain water so groundwater reserves in this region are very minimal. Groundwater in this region is often found in rock fractures [3].

The hydrogeological conditions in the Menoreh Hills have low groundwater potential. The steep slope causes rain water that is received by the land surface to gather in river channels and flow downstream rapidly. In this condition, rainwater is not infiltrated into the soil in sufficient quantities.

Meanwhile, the northern part of the study area is included in the central depressive zone which is partly located south of Borobudur Hill. This hill was part of the West Progo Dome which was broken and then sank at the end of the Tertiary Age [1]. Around the broken part, young volcanoes grew in the Quaternary Period, namely Sumbing, Merapi and Merbabu. The broken part eventually becomes the intermountainous basin and forms the ancient lake of Borobudur. These ancient lake deposits are characterized by the presence of black clay deposits [4].

4 Research Data

4.1 Field Data

Observation location data and lithology are presented in Table 1. Some examples of springs and dug wells examined are shown in Fig. 2.

Table 1. Location of research observations in Borobudur and surrounding areas.

Loc.	Coordinate		Area	pH	TDS	Lithology
	Longitude	Latitude				
S1A	110^o 11’ 13”	-7^o 37’ 09”	Karanganyar	7.4	42	Quaternary sediment
S1B	110^o 10’ 56”	-7^o 37’ 09”	Karanganyar	5.5	44	Nanggulan sandstone
R2	110^o 10’ 28”	-7^o 37’ 25”	Badrawati	9.6	31	Quaternary sediment
W3	110^o 10’ 05”	-7^o 37’ 36”	Giri Tengah	10.7	41	Quaternary sediment
R4	110^o 09’ 27”	-7^o 36’ 48”	Giri Tengah	10.8	40	Quaternary sediment
W5	110^o 10’ 28”	-7^o 36’ 52”	Ngadiharjo	5.4	94	Quaternary sediment
S6	110^o 10’ 46”	-7^o 36’ 37”	Karanganyar	8.6	37	Quaternary sediment
W7	110^o 10’ 38”	-7^o 36’ 17”	Karangrejo	5	1326	Quaternary sediment
W8	110^o 09’ 49”	-7^o 35’ 48”	Kembanglimus	4.6	134	Quaternary sediment
S9	110^o 09’ 52”	-7^o 36’ 14”	Kembanglimus	6.4	27	Quaternary sediment
W10	110^o 10’ 11”	-7^o 36’ 15”	Tawangsari	6.1	49	Quaternary sediment
W11	110^o 09’ 48”	-7^o 37’ 33”	Karangrejo	6.6	39	Nanggulan sandstone
S12	110o 10’ 14”	-7o 36’ 37”	Giri Tengah	12.6	19	Quaternary sediment
W13	110o 09’ 48”	-7o 36’ 45”	Karanganyar	7.6	99	Quaternary sediment

Table 1. (Continued)

Loc.	Coordinate		Area	pH	TDS	Litology
	Longitude	Latitude				
S14	110° 09’ 27”	-7° 37’ 11”	Ngadiharjo	5.2	93	Quaternary sediment
W15	110° 09’ 62”	-7° 37’ 26”	Ngadiharjo	4.5	79	Quaternary sediment
W16	110° 09’ 04”	-7° 36’ 51”	Giri Tengah	5.1	72	Quaternary sediment
W17	110° 08’ 48”	-7° 36’ 07”	Ngadiharjo	5.8	76	Quaternary sediment
W18	110° 08’ 48”	-7° 35’ 49”	Paripurna	5.3	56	Quaternary sediment
W19	110° 08’ 30”	-7° 36’ 56”	Paripurna	5.9	61	Andesite breccia OAF
R20	110° 08’ 22”	-7° 37’ 07”	Paripurna	5.4	48	Quaternary sediment
S21	110° 08’ 07”	-7° 36’ 52”	Paripurna	5.5	14	Quaternary sediment
S22	110° 07’ 25”	-7° 36’ 56”	Paripurna	5.2	17	Quaternary sediment
S23	110° 07’ 34”	-7° 36’ 16”	Paripurna	4.9	23	Quaternary sediment
R24	110° 08’ 25”	-7° 36’ 20”	Paripurna	5.1	15	Andesite of OAF
R25	110° 13’ 27”	-7° 37’ 35”	Paripurna	4.9	49	Nanggulan claystone
S26	110° 13’ 33”	-7° 37’ 32”	Candirejo	6,8	1430	Andesite breccia of OAF
W27	110° 13’ 22”	-7° 36’ 50”	Candirejo	6.5	165	Quaternary sediment
W28	110° 08’ 33”	-7° 37’ 01”	Candirejo	6.7	54	Quaternary sediment
W29	110° 11’ 06”	-7° 36’ 26”	Paripurna	7.4	42	Nanggulan Sandstone

Note: S: spring; W: well; R: river

Groundwater found at the S1A location (Fig. 2a) appears on the sediment, is rather turbid, brownish in color, but tasteless and odorless. Groundwater pH value is 7.4, while TDS is 42 ppm. The spring in Paripurno Village (Fig. 2b) shows odorless, clear, with a relatively acidic pH (5.5) and a low TDS (17 ppm). Different condition occurs in Candirejo spring (S26) where the groundwater shows brown, turbid, odorless but rather salty, pH 6.8 and TDS measured in the field at 1430 ppm.

Groundwater from dug wells found in Karangrejo (W7) and Kembanglimus (W8) shows colorless, clear and odorless characteristics. Groundwater in W7 tastes a bit salty, but groundwater in W8 does not taste. The measured pH in groundwater at W7 and W8 is 5 and 4.6, while the TDS is measured at 1326 and 134 ppm. The two wells tapped water from Quaternary deposits, but differed in salinity. The presence of brackish groundwater is localized. [5] mentioned that the distribution of groundwater quality in a place is not always easy to model, even the presence of brackish water is not always related to morphology.

Fig. 2. Springs found at (clockwise): a. Karanganyar Village (S1A); b. Paripurno (S22); c. Karangrejo (W7); and d. Kembanglimus (W8).

4.2 Laboratory Data

The laboratory test results of physical / chemical of groundwater are presented in Table 2. Physically, groundwater in the study area is generally tasteless to brackish, and odorless. Groundwater pH values tend to vary from normal to acidic. The groundwater studied was clear to turbid, with TDS varying from small to large enough.

The types of groundwater chemistry studied were highly variable (Table 2), namely Ca, Mg bicarbonate; Ca, Mg, alkaline - bicarbonate; alkaline, Ca - chloride and alkaline - chloride. The dominant major cations composing groundwater vary greatly, while the major anions are dominated by bicarbonate and chloride ions.

Table 2 also shows that the groundwater samples had greatly varied TDS from 119 to 6810 ppm. According to Caroll's classification (1962, in [6]) the groundwater is fresh to brackish water.

Meanwhile, the carbonate hardness of the groundwater was 6 - 16.57 ppm or <75 ppm. According to the Sawyer & Mc. Carty (1967, in [6]), it is soft groundwater. This means that there are not enough carbonate ion sources in the study area. The carbonate rocks in which groundwater passes through are only a thin layer of carbonate sandstone or claystone of the Nanggulan Formation.

Table 2 also shows that the groundwater samples had greatly varied TDS from 119 to 6810 ppm. According to Caroll's classification (1962, in [6]) the groundwater is fresh to brackish water.

Table 2. Physical / chemical data of groundwater test results in the laboratory.

No	Parameter	Sample			
		S1A	S1B	W7	S26
1	Ca^{2+} (ppm)	20.1	21.71	107.74	45.02
2	Na^{+} (ppm)	20	21	503	2294
3	K^{+} (ppm)	3	3	12	82
4	Mg^{2+} (ppm)	11.23	9.77	9.28	23.93
5	Cl^{-} (ppm)	8.5	13	1742.5	4198.7
6	HCO_3^{-} (ppm)	108.2	96.2	276.4	156.3
7	SO_4^{2-} (ppm)	6	1	88	1
8	TDS (ppm)	119	129	2840	6810
		fresh	fresh	brackish	brackish
9	pH	5.7	5.5	6.5	6.4
10	Hardness	6.30	6.00	16.57	13.69
		soft	soft	soft	soft
11	Chemical type	Ca,Mg - bicarbonate	Ca, Mg, alkaline - bicarbonate	Alkaline, Ca - chloride	Alkaline-chloride

Meanwhile, the carbonate hardness of the groundwater was 6 - 16.57 ppm or <75 ppm. According to the Sawyer & Mc. Carty (1967, in [6]), it is soft groundwater. This means that there are not enough carbonate ion sources in the study area. The carbonate rocks in which groundwater passes through are only a thin layer of carbonate sandstone or claystone of the Nanggulan Formation.

4 Hydrochemical of Groundwater

4.1 Stiff diagram Analysis

The study of water chemistry begins with looking at the chemical content of major ions in groundwater. The following Table2 are resumes of chemical elements / compounds, pH, TDS, hardness, and types of groundwater chemistry. The type of groundwater chemistry turned out to have wide variations. Considerable differences in the content of chemical elements can also be seen clearly on the Stiff diagram (Figure 3).

The dominance of the bicarbonate anion shows that groundwater in several places in the study area is generally new groundwater, which comes from precipitation in recharge area. This groundwater comes from rainwater that falls in the local area, so it has a relatively young age. However, a large alkali content indicates that there is already a process of enrichment of these elements through a hydrochemical process.

Brackish groundwater is interpreted as groundwater that has undergone evolution or enrichment in salinity. This can occur through the process of ion exchange due to the interaction / prolonged contact between groundwater to the rocks in its path [5].

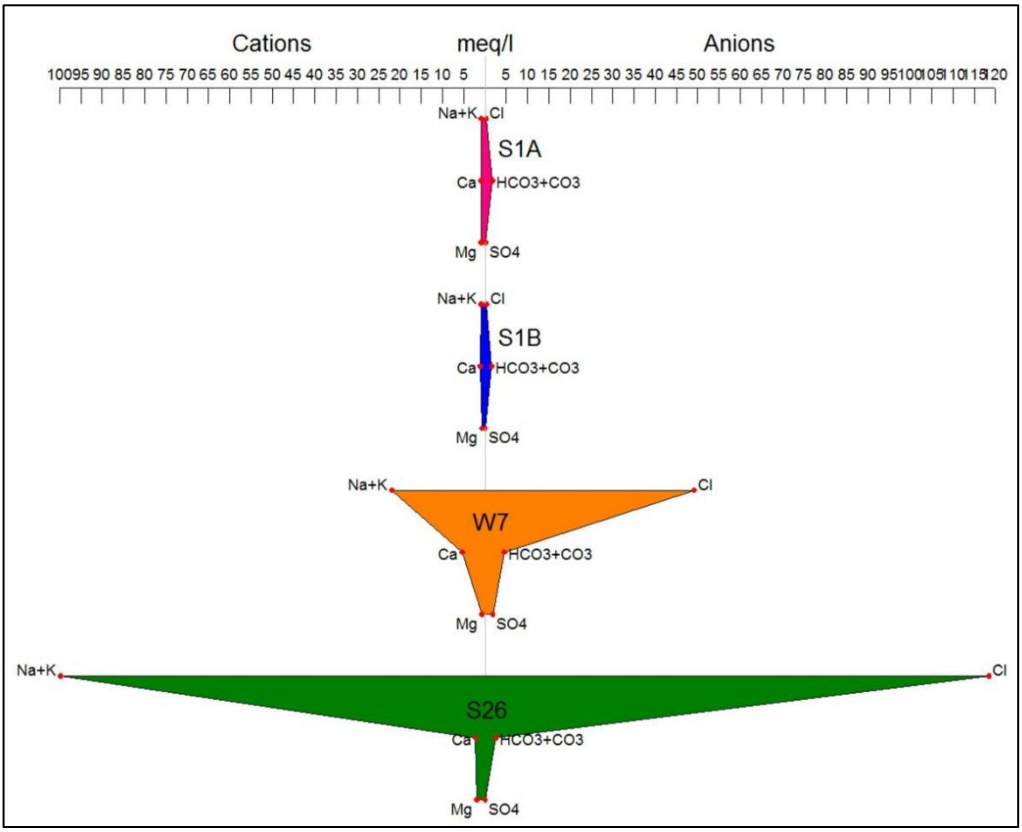

Fig. 3. Stiff diagram of groundwater samples.

4.2 Trilinier Piper Diagram Analysis

This analysis method is important for groundwater genetic studies and geochemical problems [7]. The interpretation of groundwater quality types can be determined by observing the dominant group of data plotting results in the parallelogram of Piper diagram. The chemical plots of major elements contained in the groundwater are presented in Figure 4.

According to the Piper diagram, groundwater from springs in Karanganyar (S1A, S1B) is included in 1, 3, 5 classes (Table 3), while groundwater that is found in W7 dug well (Karangrejo) and spring in S26 (Candirejo) are included in type 2, 4, and 7 water classes. From the diagram it appears that groundwater in Karanganyar is freshwater with a few mixing process. This is supported by the relatively low TDS value, which is around 119 - 129 ppm according to Carroll (1962, in [6]). The dominant processes occurring in groundwater in Karanganyar are leaching and mixing.

The groundwater from Karangrejo well and Candirejo spring is almost saline according to the Piper diagram or brackish groundwater refers to Carroll classification (1962, in [6]) with TDS 2840 and 6810 ppm. Both types of groundwater are the result of the mixing process or fossil water, but they are far from sea water intrusion process (Figure 4).

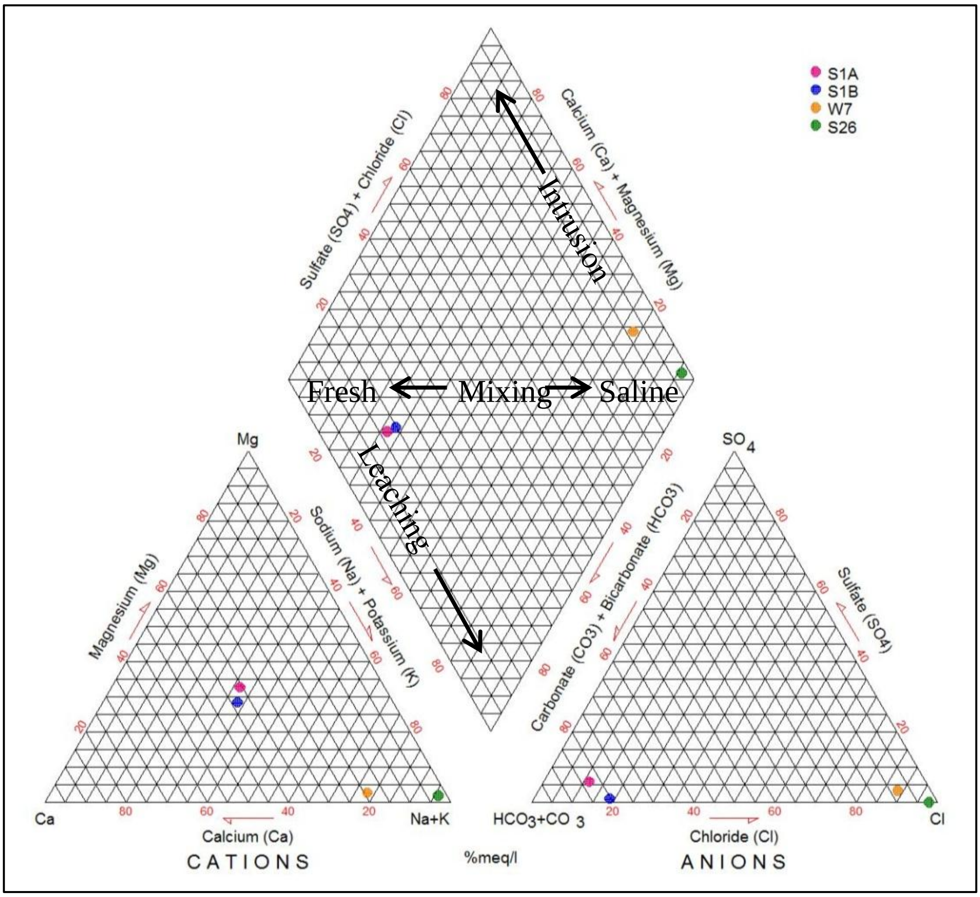

Fig. 4. Plot data of groundwater in Piper diagram.

Table 3. Types of groundwater chemistry in the study area.

Location		**Type**		**Facies**	
No	**Village**	**Cations**	**Anions**		
S1A S1B	Karanganyar	D type (No dominant type)	E type (Bicarbonate type)	1	Alkaline earths (Ca^{2+} + Mg^{2+}) exceed alkaline (Na^{+}+ K^{+}).
				3	Weak acids (CO_3^{2-} + $HCO^{-}{}_3$) exceed strong acids (SO_4^{2-} + Cl^{-}).
				5	Magnesium bicarbonate type with carbonate hardness (secondary alkalinity) > 50%, groundwater is dominated by alkaline soils (Ca^{2+} + Mg^{2+}) and weak acids (CO_3^{2-} + HCO_3^{-}).

Table 3. (Continued)

Location		Type		Facies	
No	Village	Cations	Anions		
W7 S26	Karangrejo Candirejo	C type (Sodium & potassium / Alkaline type)	G type (Chloride type)	2	Alkali ($Na^+ + K^+$) exceeds the alkaline earth ($Ca^{2+} + Mg^{2+}$).
				4	Strong acids (SO_4^{2-} + Cl^-) exceed weak acids ($CO_3^{2-} + HCO_3^-$).
				7	Sodium chloride type with non-carbonate alkali (primary salinity) > 50%, the chemical properties of groundwater are predominantly alkaline ($Na^+ + K^+$) and strong acids ($SO_4^{2-} + Cl^-$).

4.3 Piper Quadrangle Diagram Analysis

Piper's trilinier method has been developed into a quadrangle system [8] (Fig. 5), by dividing groundwater hydrochemicals into 6 hydrochemical types. According to this Piper rectangular diagram, groundwater is included in class V (fossil / connate water). Groundwater in Karanganyar is included in type Va, while groundwater in Karangrejo and Candirejo is included in type Vc.

According to Piper's quadrilateral diagram, the S1A and S1B groundwater samples from Karanganyar springs are included in the fossil water type, but are still close to group I (bicarbonate water). Groundwater is included in the Va type, although including bicarbonate facies, but this groundwater contains a fairly large alkaline elements. The presence of a large enough alkali can be sourced from feldspar minerals, clay minerals or rock fragments (Bowen, 1986 in [9]). Feldspar minerals are easily weathered silicate minerals, according to Goldich sequence weathering (Goldich, 1938, in [10]).

Although dominated by bicarbonate ions, groundwater in Karanganyar is not solely supplied by rainwater, but there is a cation exchange process that accompanies it. This condition is very likely to occur, because the local aquifer is clayey Quaternary sediments. These sediments are generally part of ancient lake sediments [4]. The tendency of groundwater to be of type Va is much controlled by the cation exchange process. The ion exchange processes in groundwater particularly occur in clay minerals [11]. The high salinity in the groundwater can also be supported by the existence of a deaquation process (Drever, 1988 in [12]). Some salt / brackish water events can also occur due to salt concentration through the process of salt sieving in fine-grained sediments [13].

4.4 Durov Diagram Analysis

The Durov diagram is almost similar to the Piper diagram because it also uses a trilinier diagram. In this diagram we can see the existence of a hydrochemical process that mainly occurs in the study area (Fig. 6).

The groundwater sample plot from the Karanganyar spring enters area 2 in the diagram which means that the groundwater has the dominant characteristics of HCO_3^-, Ca^{2+} and Mg^{2+} which are quite large, associated with certain minerals. Ca^{2+} and Na^+ are an important part of the ion exchange process [13]. In addition to ion exchange, groundwater in the Karanganyar area undergoes a simple dissolution or mixing process.

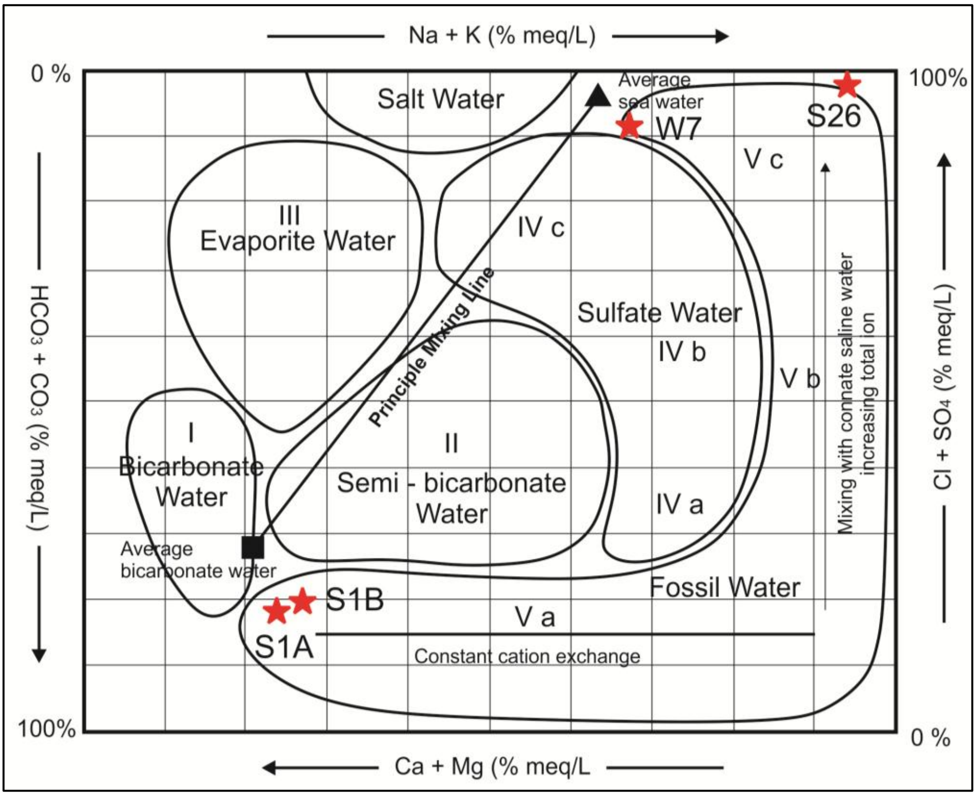

Fig. 5. The hydrochemical type of groundwater on a rectangular Piper diagram.

The groundwater samples from the Karangrejo well and Candirejo springs enter area 9, which means that the groundwater is the result of an advanced process of simple dissolution or mixing. This area shows that Cl^- and Na^+ are dominant and often mark end-point waters.

The Durov diagram shows that the ion exchange process is an important process in freshwater in the study area. This might happen to Quaternary volcanic rocks or sediments which contain a lot of clay minerals. Porous geological material composed of a number of colloidal sized particles such as clay minerals has the ability to exchange ions that are absorbed on the particle surface. Clay minerals generally exhibit surface charges due to ion substitution [14]. The tendency of ion adsorption depends on the pH of the solution. Variations in the number and types of ions will reflect the composition of ions in the clayey sediments.

The simple dissolution or mixing process shown in brackish groundwater at Karangrejo and Candirejo is supported by clay material derived from Quaternary sediments or weathered volcanic breccia of the Old Andesite Formation. The process can take a long time so that the evolution of anions tend to be the hydrochemical type of sea water.

Rocks in the study area can function as aquifers. The results of weathered aquifer and non-aquifer rocks can produce clay material that supports the ion exchange process. The aquifer found in Karanganyar shows the size of sand grains with high porosity and permeability, supported by intergrain pores. Many springs in the study area are supported by Quaternary aquifer like this conditions. In addition to Quaternary deposits, compact rocks such as OAF andesite breccias and Nanggulan sandstones can also function as aquifers.

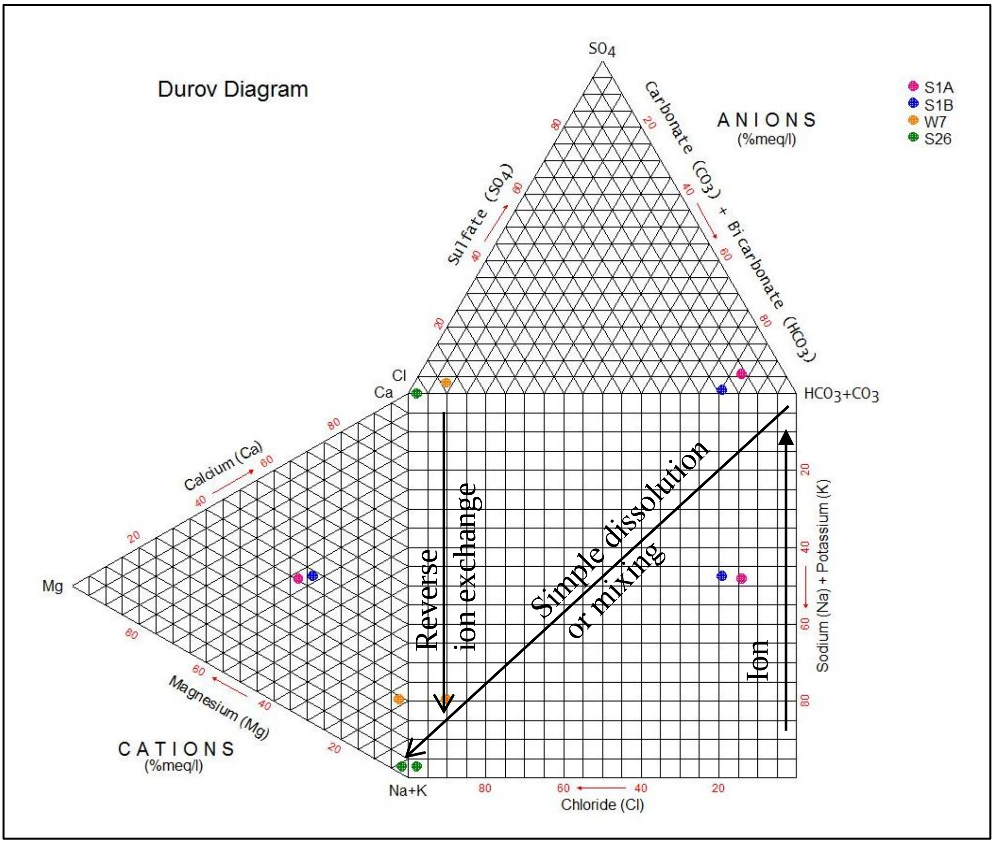

Fig. 6. Plot of groundwater data in Durov diagram (Lloyd & Heathcote, 1985).

Based on several analyzes before, it appears that groundwater in the study area has a wide variation in chemical types. This is influenced by the varying hydrochemical processes as groundwater travel below the surface.The existence of fresh groundwater is usually associated with local precipitation where rainfall still dominates the type of groundwater chemistry. Groundwater in Karanganyar with bicarbonate facies is young groundwater but there is already an influence on the process of alkaline ion enrichment of soluble mineral feldspar through long water-rock interaction.

Meanwhile, brackish water can be caused by ion exchange processes in Quaternary clay deposits or claystone that can affect groundwater quality through water-rock interaction process. This is supported by the presence of Nanggulan claystone around the Candirejo spring. The process of ion exchange between groundwater and rocks in its path is very easy to occur in clay minerals [12].

The presence of alkali ions (Na, K) is quite dominant in groundwater is usually comes from the weathering of silicate rocks [10]. Furthermore, Grim (1953, in Listyani, 2016a) says that the weathering process is an example of an ion exchange process that involves the release of alkali or alkaline earth ions. It may be mainly controlled by weathering and balance of evaporation-precipitation conditions [15]. Feldspar is an influential source of alkaline ions [12]. A longer period of water-rock reaction can occur as long as groundwater flows below the surface and results in the enrichment of ions in it.

5 Summary

Groundwater in the study area has a cation element that varies from one place to another, with the dominant anion of bicarbonate or chloride. The types of groundwater chemistry in the study area varied greatly including Ca, Mg - bicarbonate; Ca, Mg, alkaline - bicarbonate; alkaline, Ca-chloride and alkaline chloride.

Groundwater salinity in the study area varies from fresh to brackish. The chemical content of the goundwater in Karanganyar is supported by low TDS, freshwater with type Va. The dominance of bicarbonate ions shows that this groundwater is much influenced by precipitation, but there are already indications of mixing or ion exchange processes. This groundwater is young which is affected by the process of long enough water - rocks interaction or soluble minerals. The physical / chemical character of groundwater is influenced by the presence of Old Andesite and Nanggulan Formation rocks as well as clay deposits which support the cation exchange process.

Brackish groundwater is also found in the Vc type in research areas, especially in Karangrejo and Candirejo. This groundwater has a high TDS, but is still soft. The groundwater is the result of simple dissolution or mixing processes in the advanced phase. The process of ion exchange and mixing with fossil water is also possible in this area. The ion exchange process develops because of the large amount of clay content in Quaternary deposits.

Acknowledgment

This paper is based on the results of research in 2016 by funding of Kopertis V Yogyakarta, therefore the authors would like to thank for the support of Kopertis V and STTNAS Yogyakarta so that this paper can be completed.

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Chemical Type Variation of Groundwater in Borobudur and Its Surrounding Areas, Magelang District

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Abstract. Hydrogeological surveys have been carried out in the Borobudur area and its surroundings, the northern part of the West Progo Hills to the Magelang intermountain plains. The purpose of this study is to determine the variations in groundwater's chemical types in the study area and to interpret the hydrochemical processes. Primary data was taken in the field, including groundwater data and rock petrology. Physical / chemical data of groundwater were obtained from laboratory test results. Data analysis includes hydrochemical analysis using the Stiff, Piper, and Durov diagrams. The result shows that groundwater in the study area has a wide variety of chemical types, namely Ca, Mg - bicarbonate; Ca, Mg, alkaline – bicarbonate; Alkaline, Ca – chloride, and Alkaline - chloride. Groundwater in the study area is fresh (type Va) to brackish (type Vc), with low - moderate TDS content (119 - 6,810 ppm), and soft calcium carbonate hardness (6.0 - 16.6 ppm). Hydrochemical processes occur in groundwater are simple dissolution and cation exchange caused by clay materials originating from Quaternary deposits or weathering of Old Andesite Formation volcanic breccia. In addition, the presence of brackish water in Karangrejo and Candirejo may be triggered by mixing with fossil water.

1 Introduction

The research area is located in Borobudur and its surroundings, Magelang Regency (Fig. 1), which is included in the southern part of the Mungkid sheet map. Geographically, the study area is included in the coordinates 110^{o}7'15 "- 110^{o}13'45" South Latitude and 7^{o}35'45 "- 7^{o}37'40" East Longitude.

The northern research area is included in the physiography of the Java central depression or intra mountain of the Quaternary volcano, while the southern part is included in the West Progo Hills [1]. West Progo Hills physiography is a non-groundwater basin region [2]. In this area, groundwater can be found with varying quantity and quality.

In quantity, groundwater is generally quite abundant in alluvial / coluvial deposits, and only a few can be extracted from hard rock. Meanwhile, groundwater quality also shows variations from fresh to brackish. This varying quality of groundwater is characterized by different types of groundwater chemistry.

Determination of the type of groundwater chemistry becomes important in hydrogeological studies. By knowing the type of groundwater chemistry, we can also provide recommendations for groundwater quality that are suitable for the local community's purpose. Good groundwater quality will have a certain type of groundwater

chemistry, with certain major elemental content, according to the limits recommended by the government.

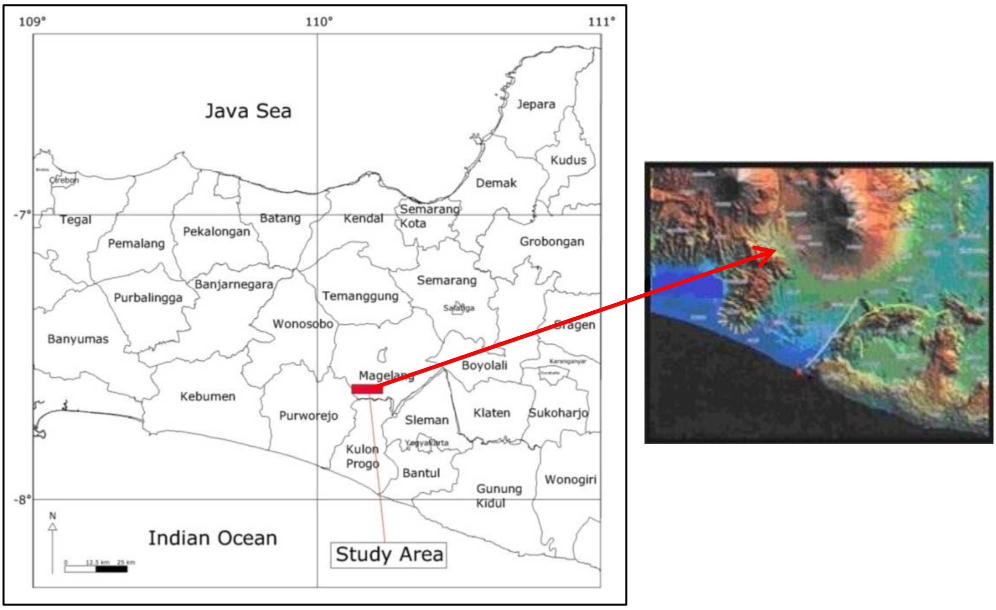

Fig. 1. Research area in Borobudur and its vicinity, Central Java

2 Method

Hydrogeological surveys in the field are conducted to determine the condition of groundwater resources in the study area. This survey was conducted to retrieve the geological data of the study area to obtain an overview of the geological characteristics and groundwater potential. Groundwater sampling was carried out at springs and dug well at four locations. Selected springs are moderate or large discharge springs.

Physical / chemical of groundwater laboratory tests were carried out at BBTKLP Yogyakarta Laboratory. Meanwhile, petrological data were obtained directly in the field as well as laboratory descriptions of rock samples. The primary data then analyzed to determine variations in the type of groundwater chemistry and the interpretation of hydrogeological processes using the Stiff, Piper and Durov diagrams.

3 Regional Geology of Research Area

The geology of the research area on the West Progo Hills physiography is dominated by materials in the form of Old Andesite Formation (OAF) andesite breccias, tuffs, lapilli tuffs, agglomerates, and intercalation of andesite lava flows and Nanggulan sedimentary rocks (sandstones, claystone). The OAF rocks were formed by ancient volcanic activity in the Tertiary and impermeable. As a result, these materials are not able to store and drain water so groundwater reserves in this region are very minimal. Groundwater in this region is often found in rock fractures [3].

The hydrogeological conditions in the Menoreh Hills have low groundwater potential. The steep slope causes rain water that is received by the land surface to gather in river channels and flow downstream rapidly. In this condition, rainwater is not infiltrated into the soil in sufficient quantities.

Meanwhile, the northern part of the study area is included in the central depressive zone which is partly located south of Borobudur Hill. This hill was part of the West Progo Dome which was broken and then sank at the end of the Tertiary Age [1]. Around the broken part, young volcanoes grew in the Quaternary Period, namely Sumbing, Merapi and Merbabu. The broken part eventually becomes the intermountainous basin and forms the ancient lake of Borobudur. These ancient lake deposits are characterized by the presence of black clay deposits [4].

4 Research Data

4.1 Field Data

Observation location data and lithology are presented in Table 1. Some examples of springs and dug wells examined are shown in Fig. 2.

Table 1. Location of research observations in Borobudur and surrounding areas.

Loc.	**Coordinate**		**Area**	**pH**	**TDS**	**Lithology**
	Longitude	**Latitude**				
S1A	110^{o} 11’ 13”	-7^{o} 37’ 09”	Karanganyar	7.4	42	Quaternary sediment
S1B	110^{o} 10’ 56”	-7^{o} 37’ 09”	Karanganyar	5.5	44	Nanggulan sandstone
R2	110^{o} 10’ 28”	-7^{o} 37’ 25”	Badrawati	9.6	31	Quaternary sediment
W3	110^{o} 10’ 05”	-7^{o} 37’ 36”	Giri Tengah	10.7	41	Quaternary sediment
R4	110^{o} 09’ 27”	-7^{o} 36’ 48”	Giri Tengah	10.8	40	Quaternary sediment
W5	110^{o} 10’ 28”	-7^{o} 36’ 52”	Ngadiharjo	5.4	94	Quaternary sediment
S6	110^{o} 10’ 46”	-7^{o} 36’ 37”	Karanganyar	8.6	37	Quaternary sediment
W7	110^{o} 10’ 38”	-7^{o} 36’ 17”	Karangrejo	5	1326	Quaternary sediment
W8	110^{o} 09’ 49”	-7^{o} 35’ 48”	Kembanglimus	4.6	134	Quaternary sediment
S9	110^{o} 09’ 52”	-7^{o} 36’ 14”	Kembanglimus	6.4	27	Quaternary sediment
W10	110^{o} 10’ 11”	-7^{o} 36’ 15”	Tawangsari	6.1	49	Quaternary sediment
W11	110^{o} 09’ 48”	-7^{o} 37’ 33”	Karangrejo	6.6	39	Nanggulan sandstone
S12	110^{o} 10’ 14”	-7o 36’ 37”	Giri Tengah	12.6	19	Quaternary sediment
W13	110^{o} 09’ 48”	-7o 36’ 45”	Karanganyar	7.6	99	Quaternary sediment

Table 1. (Continued)

Loc.	Coordinate		Area	pH	TDS	Litology
	Longitude	Latitude				
S14	110° 09’ 27”	-7° 37’ 11”	Ngadiharjo	5.2	93	Quaternary sediment
W15	110° 09’ 62”	-7° 37’ 26”	Ngadiharjo	4.5	79	Quaternary sediment
W16	110° 09’ 04”	-7° 36’ 51”	Giri Tengah	5.1	72	Quaternary sediment
W17	110° 08’ 48”	-7° 36’ 07”	Ngadiharjo	5.8	76	Quaternary sediment
W18	110° 08’ 48”	-7° 35’ 49”	Paripurna	5.3	56	Quaternary sediment
W19	110° 08’ 30”	-7° 36’ 56”	Paripurna	5.9	61	Andesite breccia OAF
R20	110° 08’ 22”	-7° 37’ 07”	Paripurna	5.4	48	Quaternary sediment
S21	110° 08’ 07”	-7° 36’ 52”	Paripurna	5.5	14	Quaternary sediment
S22	110° 07’ 25”	-7° 36’ 56”	Paripurna	5.2	17	Quaternary sediment
S23	110° 07’ 34”	-7° 36’ 16”	Paripurna	4.9	23	Quaternary sediment
R24	110° 08’ 25”	-7° 36’ 20”	Paripurna	5.1	15	Andesite of OAF
R25	110° 13’ 27”	-7° 37’ 35”	Paripurna	4.9	49	Nanggulan claystone
S26	110° 13’ 33”	-7° 37’ 32”	Candirejo	6,8	1430	Andesite breccia of OAF
W27	110° 13’ 22”	-7° 36’ 50”	Candirejo	6.5	165	Quaternary sediment
W28	110° 08’ 33”	-7° 37’ 01”	Candirejo	6.7	54	Quaternary sediment
W29	110° 11’ 06”	-7° 36’ 26”	Paripurna	7.4	42	Nanggulan Sandstone

Note: S: spring; W: well; R: river

Groundwater found at the S1A location (Fig. 2a) appears on the sediment, is rather turbid, brownish in color, but tasteless and odorless. Groundwater pH value is 7.4, while TDS is 42 ppm. The spring in Paripurno Village (Fig. 2b) shows odorless, clear, with a relatively acidic pH (5.5) and a low TDS (17 ppm). Different condition occurs in Candirejo spring (S26) where the groundwater shows brown, turbid, odorless but rather salty, pH 6.8 and TDS measured in the field at 1430 ppm.

Groundwater from dug wells found in Karangrejo (W7) and Kembanglimus (W8) shows colorless, clear and odorless characteristics. Groundwater in W7 tastes a bit salty, but groundwater in W8 does not taste. The measured pH in groundwater at W7 and W8 is 5 and 4.6, while the TDS is measured at 1326 and 134 ppm. The two wells tapped water from Quaternary deposits, but differed in salinity. The presence of brackish groundwater is localized. That the distribution of groundwater quality in a place is not always easy to model [5], even the presence of brackish water is not always related to morphology.

Fig. 2. Springs found at (clockwise): a. Karanganyar Village (S1A); b. Paripurno (S22); c. Karangrejo (W7); and d. Kembanglimus (W8).

4.2 Laboratory Data

The laboratory test results of physical / chemical of groundwater are presented in Table 2. Physically, groundwater in the study area is generally tasteless to brackish, and odorless. Groundwater pH values tend to vary from normal to acidic. The groundwater studied was clear to turbid, with TDS varying from small to large enough.

The types of groundwater chemistry studied were highly variable (Table 2), namely Ca, Mg bicarbonate; Ca, Mg, alkaline - bicarbonate; alkaline, Ca - chloride and alkaline - chloride. The dominant major cations composing groundwater vary greatly, while the major anions are dominated by bicarbonate and chloride ions.

Table 2 also shows that the groundwater samples had greatly varied TDS from 119 to 6810 ppm. According to Caroll's classification (1962, in [6]) the groundwater is fresh to brackish water.

Meanwhile, the carbonate hardness of the groundwater was 6 - 16.57 ppm or <75 ppm. According to the Sawyer & Mc. Carty (1967, in [6]), it is soft groundwater. This means that there are not enough carbonate ion sources in the study area. The carbonate rocks in which groundwater passes through are only a thin layer of carbonate sandstone or claystone of the Nanggulan Formation.

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Table 2. Physical / chemical data of groundwater test results in the laboratory.

No	Parameter	Sample			
		S1A	**S1B**	**W7**	**S26**
1	Ca^{2+} (ppm)	20.1	21.71	107.74	45.02
2	Na^{+} (ppm)	20	21	503	2294
3	K^{+} (ppm)	3	3	12	82
4	Mg^{2+} (ppm)	11.23	9.77	9.28	23.93
5	Cl^{-} (ppm)	8.5	13	1742.5	4198.7
6	HCO_3^{-} (ppm)	108.2	96.2	276.4	156.3
7	SO_4^{2-} (ppm)	6	1	88	1
8	TDS (ppm)	119	129	2840	6810
		fresh	fresh	brackish	brackish
9	pH	5.7	5.5	6.5	6.4
10	Hardness	6.30	6.00	16.57	13.69
		soft	soft	soft	soft
11	Chemical type	Ca,Mg - bicarbonate	Ca, Mg, alkaline - bicarbonate	Alkaline, Ca - chloride	Alkaline-chloride

Meanwhile, the carbonate hardness of the groundwater was 6 - 16.57 ppm or <75 ppm. According to the Sawyer & Mc. Carty (1967, in [6]), it is soft groundwater. This means that there are not enough carbonate ion sources in the study area. The carbonate rocks in which groundwater passes through are only a thin layer of carbonate sandstone or claystone of the Nanggulan Formation.

4 Hydrochemical of Groundwater

4.1 Stiff diagram Analysis

The study of water chemistry begins with looking at the chemical content of major ions in groundwater. Table 2 above is the resume of chemical elements / compounds, pH, TDS, hardness, and types of groundwater chemistry. The type of groundwater chemistry turned out to have wide variations. Considerable differences in the content of chemical elements can also be seen clearly on the Stiff diagram (Figure 3).

The dominance of the bicarbonate anion shows that groundwater in several places in the study area is generally new groundwater, which comes from precipitation in recharge area. This groundwater comes from rainwater that falls in the local area, so it has a relatively young age. However, a large alkali content indicates that there is already a process of enrichment of these elements through a hydrochemical process.

Brackish groundwater is interpreted as groundwater that has undergone evolution or enrichment in salinity. This can occur through the process of ion exchange due to the interaction / prolonged contact between groundwater to the rocks in its path [5].

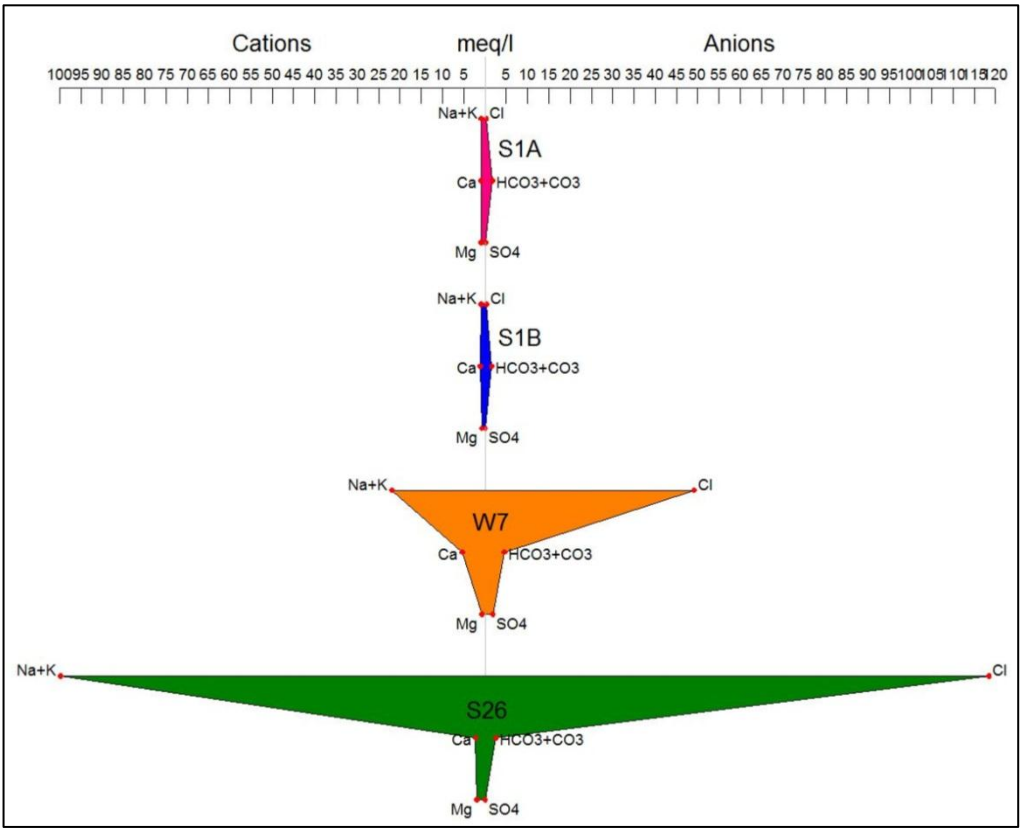

Fig. 3. Stiff diagram of groundwater samples.

4.2 Trilinier Piper Diagram Analysis

This analysis method is important for groundwater genetic studies and geochemical problems [7]. The interpretation of groundwater quality types can be determined by observing the dominant group of data plotting results in the parallelogram of Piper diagram. The chemical plots of major elements contained in the groundwater are presented in Figure 4.

According to the Piper diagram, groundwater from springs in Karanganyar (S1A, S1B) is included in 1, 3, 5 classes (Table 3), while groundwater that is found in W7 dug well (Karangrejo) and spring in S26 (Candirejo) are included in type 2, 4, and 7 water classes. From the diagram it appears that groundwater in Karanganyar is freshwater with a few mixing process. This is supported by the relatively low TDS value, which is around 119 - 129 ppm according to Carroll (1962, in [6]). The dominant processes occurring in groundwater in Karanganyar are leaching and mixing.

The groundwater from Karangrejo well and Candirejo spring is almost saline according to the Piper diagram or brackish groundwater refers to Carroll classification (1962, in [6]) with TDS 2840 and 6810 ppm. Both types of groundwater are the result of the mixing process or fossil water, but they are far from sea water intrusion process (Figure 4).

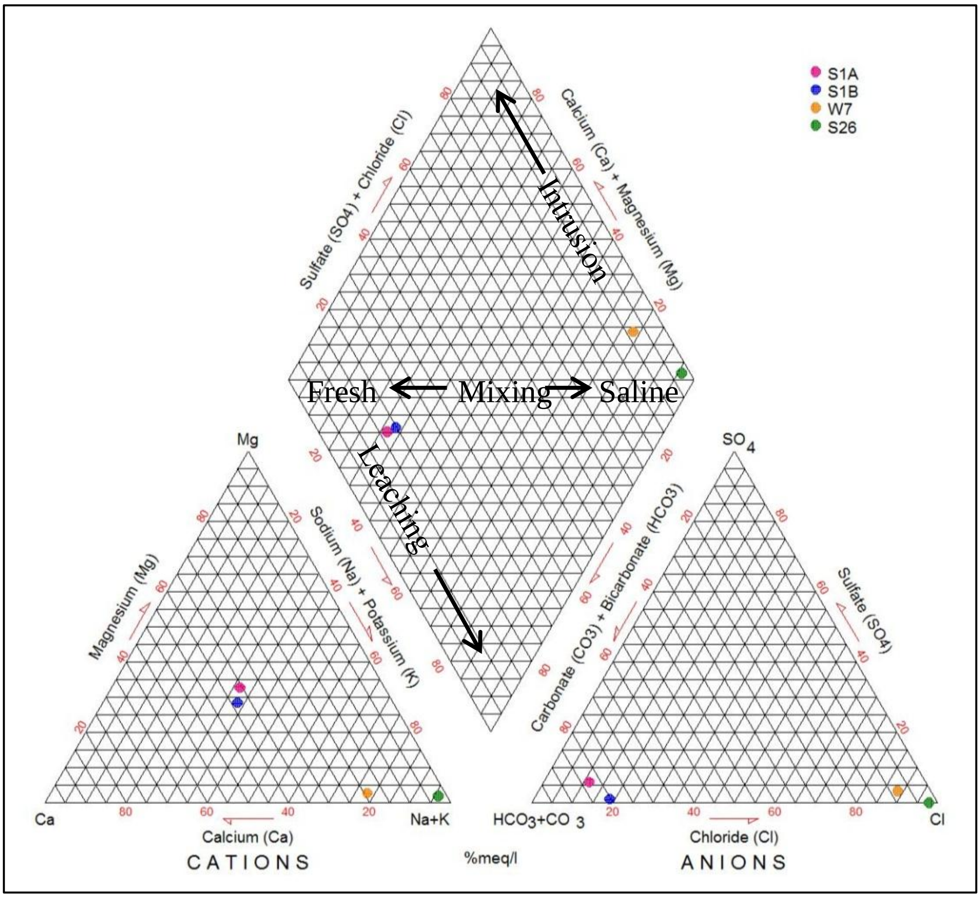

Fig. 4. Plot data of groundwater in Piper diagram.

Table 3. Types of groundwater chemistry in the study area.

Location		Type		Facies	
No	**Village**	**Cations**	**Anions**		
S1A S1B	Karanganyar	D type (No dominant type)	E type (Bicarbonate type)	1	Alkaline earths ($Ca^{2+} + Mg^{2+}$) exceed alkaline ($Na^{+} + K^{+}$).
				3	Weak acids ($CO_3^{2-} + HCO^{-}_3$) exceed strong acids ($SO_4^{2-} + Cl^{-}$).
				5	Magnesium bicarbonate type with carbonate hardness (secondary alkalinity) > 50%, groundwater is dominated by alkaline soils (Ca^{2+} + Mg^{2+}) and weak acids (CO_3^{2-} + HCO_3^{-}).

Table 3. (Continued)

Location		Type		Facies	
No	Village	Cations	Anions		
W7 S26	Karangrejo Candirejo	C type (Sodium & potassium / Alkaline type)	G type (Chloride type)	2	Alkali ($Na^+ + K^+$) exceeds the alkaline earth ($Ca^{2+} + Mg^{2+}$).
				4	Strong acids (SO_4^{2-} + Cl^-) exceed weak acids ($CO_3^{2-} + HCO_3^-$).
				7	Sodium chloride type with non-carbonate alkali (primary salinity) > 50%, the chemical properties of groundwater are predominantly alkaline ($Na^+ + K^+$) and strong acids ($SO_4^{2-} + Cl^-$).

4.3 Piper Quadrangle Diagram Analysis

Piper's trilinier method has been developed into a quadrangle system [8] (Fig. 5), by dividing groundwater hydrochemicals into 6 hydrochemical types. According to this Piper rectangular diagram, groundwater is included in class V (fossil / connate water). Groundwater in Karanganyar is included in type Va, while groundwater in Karangrejo and Candirejo is included in type Vc.

According to Piper's quadrilateral diagram, the S1A and S1B groundwater samples from Karanganyar springs are included in the fossil water type, but are still close to group I (bicarbonate water). Groundwater is included in the Va type, although including bicarbonate facies, but this groundwater contains a fairly large alkaline elements. The presence of a large enough alkali can be sourced from feldspar minerals, clay minerals or rock fragments (Bowen, 1986 in [9]). Feldspar minerals are easily weathered silicate minerals, according to Goldich sequence weathering (Goldich, 1938, in [10]).

Although dominated by bicarbonate ions, groundwater in Karanganyar is not solely supplied by rainwater, but there is a cation exchange process that accompanies it. This condition is very likely to occur, because the local aquifer is clayey Quaternary sediments. These sediments are generally part of ancient lake sediments [4]. The tendency of groundwater to be of type Va is much controlled by the cation exchange process. The ion exchange processes in groundwater particularly occur in clay minerals [11].

Groundwater in Karangrejo (W7) and Candirejo (S26) are included in class Vc. This class indicate mixing with connate water processes, which may come from black clay of ancient Borobudur lake sediments. The high salinity in the groundwater can also be supported by the existence of a deaquation process (Drever, 1988 in [12]). Some salt / brackish water events can also occur due to salt concentration through the process of salt sieving in fine-grained sediments [13].

4.4 Durov Diagram Analysis

The Durov diagram is almost similar to the Piper diagram because it also uses a trilinier diagram. In this diagram we can see the existence of a hydrochemical process that mainly occurs in the study area (Fig. 6).

The groundwater sample plot from the Karanganyar spring enters middle right area in the diagram which means that the groundwater has the dominant characteristics of HCO_3^-, Ca^{2+} and Mg^{2+} which are quite large, associated with certain minerals. Ca^{2+} and Na^+ are an important part of the ion exchange process [13]. In addition to ion exchange, groundwater in the Karanganyar area undergoes a simple dissolution or mixing process.

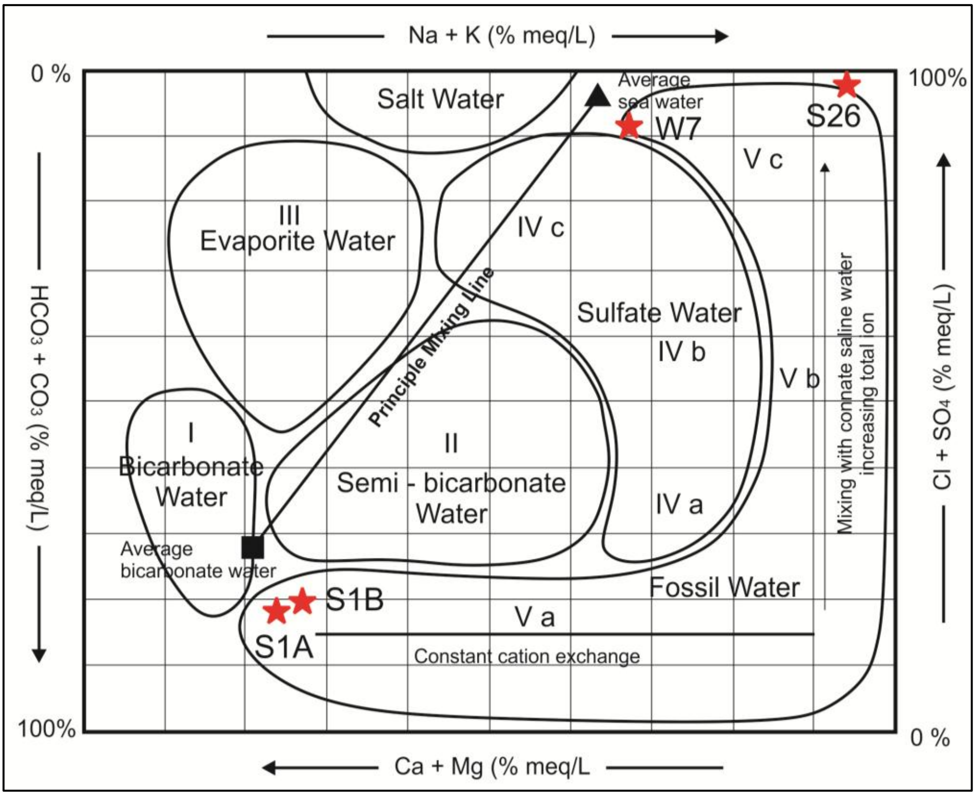

Fig. 5. The hydrochemical type of groundwater on a rectangular Piper diagram [8].

The groundwater samples from the Karangrejo well and Candirejo springs enter bottom left area, which means that the groundwater is the result of an advanced process of simple dissolution or mixing. This area shows that Cl^- and Na^+ are dominant and often mark end-point waters.

The Durov diagram shows that the ion exchange process is an important process in freshwater in the study area. This might happen to Quaternary volcanic rocks or sediments which contain a lot of clay minerals. Porous geological material composed of a number of colloidal sized particles such as clay minerals has the ability to exchange ions that are absorbed on the particle surface. Clay minerals generally exhibit surface charges due to ion substitution [14]. The tendency of ion adsorption depends on the pH of the solution. Variations in the number and types of ions will reflect the composition of ions in the clayey sediments.

The simple dissolution or mixing process shown in brackish groundwater at Karangrejo and Candirejo is supported by clay material derived from Quaternary sediments or weathered volcanic breccia of the Old Andesite Formation. The process can take a long time so that the evolution of anions tend to be the hydrochemical type of sea water.

Rocks in the study area can function as aquifers. The results of weathered aquifer and non-aquifer rocks can produce clay material that supports the ion exchange process. The aquifer found in Karanganyar shows the size of sand grains with high porosity and permeability, supported by intergrain pores. Many springs in the study area are supported by Quaternary aquifer like this conditions. In addition to Quaternary deposits, compact rocks such as OAF andesite breccias and Nanggulan sandstones can also function as aquifers.

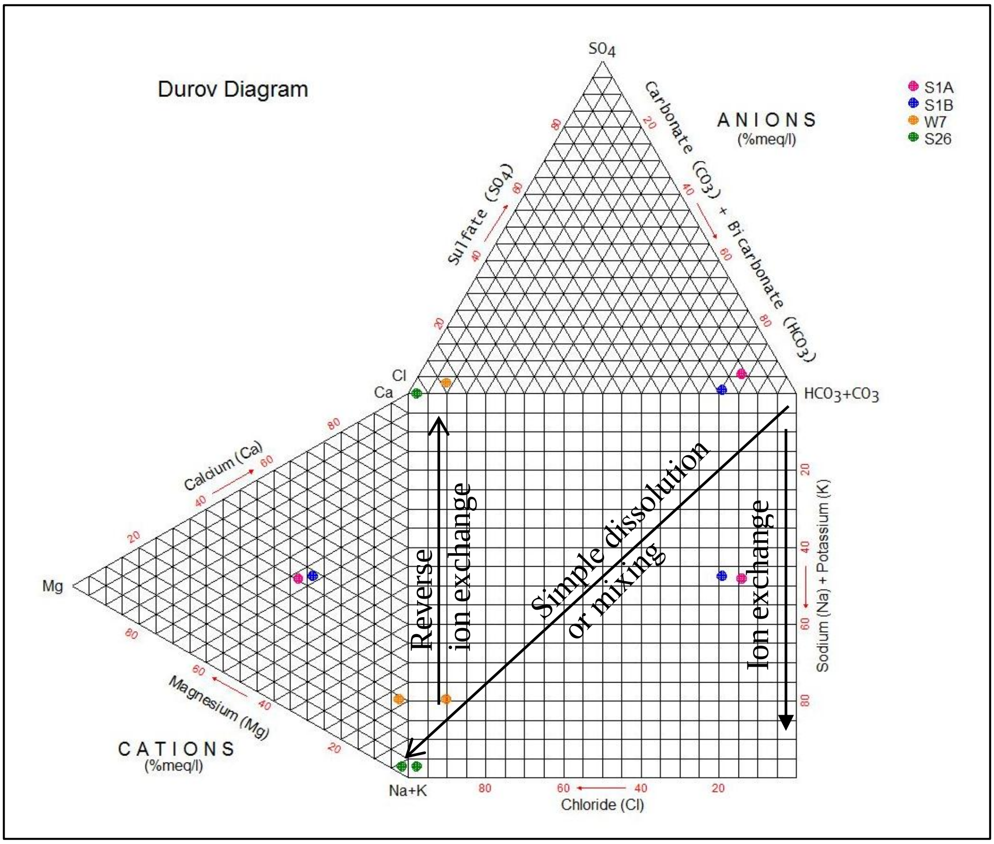

Fig. 6. Plot of groundwater data in Durov diagram [13].

Based on several analyzes before, it appears that groundwater in the study area has a wide variation in chemical types. This is influenced by the varying hydrochemical processes as groundwater travel below the surface.The existence of fresh groundwater is usually associated with local precipitation where rainfall still dominates the type of groundwater chemistry. Groundwater in Karanganyar with bicarbonate facies is young groundwater but there is already an influence on the process of alkaline ion enrichment of soluble mineral feldspar through long water-rock interaction.

Meanwhile, brackish water can be caused by ion exchange processes in Quaternary clay deposits or claystone that can affect groundwater quality through water-rock interaction process. This is supported by the presence of Nanggulan claystone around the Candirejo spring. The process of ion exchange between groundwater and rocks in its path is very easy to occur in clay minerals [12]. It is also supported by black clay deposits of ancient Borobudur Lake dediments.

The presence of alkali ions (Na, K) is quite dominant in groundwater is usually comes from the weathering of silicate rocks [10]. Furthermore, Grim (1953, in Listyani, 2016a) says that the weathering process is an example of an ion exchange process that involves the release of alkali or alkaline earth ions. It may be mainly controlled by weathering and balance of evaporation-precipitation conditions [15]. Feldspar is an influential source of alkaline ions [12]. A longer period of water-rock reaction can occur as long as groundwater flows below the surface and results in the enrichment of ions in it.

5 Summary

Groundwater in the study area has a cation element that varies from one place to another, with the dominant anion of bicarbonate or chloride. The types of groundwater chemistry in the study area varied greatly including Ca, Mg - bicarbonate; Ca, Mg, alkaline - bicarbonate; alkaline, Ca-chloride and alkaline chloride.

Groundwater salinity in the study area varies from fresh to brackish. The chemical content of the goundwater in Karanganyar is supported by low TDS, freshwater with type Va. The dominance of bicarbonate ions shows that this groundwater is much influenced by precipitation, but there are already indications of mixing or ion exchange processes. This groundwater is young which is affected by the process of long enough water - rocks interaction or soluble minerals. The physical / chemical character of groundwater is influenced by the presence of Old Andesite and Nanggulan Formation rocks as well as clay deposits which support the cation exchange process.

Brackish groundwater is also found in the Vc type in research areas, especially in Karangrejo and Candirejo. This groundwater has a high TDS, but is still soft. The groundwater is the result of simple dissolution or mixing processes in the advanced phase. The process of ion exchange and mixing with fossil water is also possible in this area. The ion exchange process develops because of the large amount of clay content in Quaternary deposits, and may be supported by black clay of ancient Borobudur Lake sediments.

Acknowledgment

This paper is based on the results of research in 2016 by funding of Kopertis V Yogyakarta, therefore the authors would like to thank for the support of Kopertis V and STTNAS Yogyakarta so that this paper can be completed.

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