Hydrogeochemistry of springwater in Leuwisari subdistrict and surrounding, Tasikmalaya, West Java, Indonesia

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ABSTRACT

The southern foot slope of the Galunggung volcano in Leuwisari subdistrict and surrounding, Tasikmalaya, Indonesia, is abundant in springs. These springs are crucial to the community since they provide water for both domestic and agricultural purposes. However, the hydraulic connection between these springs is still unknown. This study aims to investigate the hydraulic connectivity of springs based on their chemical composition in response to the problem. In order to achieve the goals, the physicochemical characteristics and geochemistry of eight spring in the research region were investigated. The chemical composition of water was classified using the Kurlov formula and presented using fingerprint, composition, and Piper diagrams. The results indicate that the chemical compositions of all spring samples are almost the same and do not change considerably for most characteristics from upstream to downstream, with Cijambe spring being the lone exception. Based on this situation, it is possible to deduce that the Cijambe spring is associated with the shallow aquifer system. Meanwhile, the other seven springs are hydrologically related and associated with the deeper aquifer system. On the other hand, all spring water may originate from a weathered basalt, as shown by the springwater geochemistry assessment. Therefore, the water facies of spring in the study area is mainly classified as Ca-Mg-HCO_3 water. Finally, the hydraulic connectivity of these springs may serve as the basis for the management and development of groundwater in the study area.

Keywords: *Hydrogeochemistry, Spring, Hydraulic Connectivity*

1. INTRODUCTION

In recent decades, the rate of population increase in Tasikmalaya Regency and Tasikmalaya City, West Java, Indonesia, has been exceptional. This region's population increased from 2,300,000 in 2008 to 2,600,000 by 2021 [1], [2]. The population of Tasikmalaya is anticipated to expand by 0.97 percent every year until 2045 when it will reach 3,300,000 people. As the population increases, the need for clean water will increase.

The primary piped drinking water source for this region's residents is groundwater, particularly springwater. The existing production capacity of Tasikmalaya Municipal Waterworks (i.e., PDAM Tasikmalaya) is 521 l/s, of which 90% comes from springs [3]. However, the connectivity among these water resources has not been identified and understood thoroughly. Therefore, for better management, it is necessary to understand the hydraulic conductivity of the aquifer from which these springs originate.

According to some research, multivariate statistical techniques may successfully extract vital information from hydrochemical datasets in complex systems [4], [5]. These approaches may assist in resolving hydrological parameters such as aquifer borders, groundwater flow pathways, or hydrochemical components, identifying the effect of rock chemistry on water composition, and isolating anomalies such as human-made impacts from the background.

The chemistry of springwaters represents the interaction of groundwater with the host geology of the aquifer, as well as any chemical components that may be

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introduced from surface sources [6]. The facies of groundwater reflect both the chemical processes happening within the lithologic framework and the flow pattern of the water [7]. The classification of groundwater is based on the common cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (HCO_3^{-}, SO_4^{2-}, and Cl^{-}) found in springwater [6]. Excluding the effects of human activities, the chemical composition of surface water and groundwater is determined by a number of variables, such as the composition of precipitation, the mineralogy of the watershed and aquifers, climate, and altitude [4].

Hydrogeochemical data to investigate aquifer's hydraulic conductivity has been studied in several geological settings across the globe. Typically, the samples are divided into groups with comparable chemical features (hydrochemical facies), which may subsequently be associated with their geographic location. The observed regional variability may provide information on the heterogeneity and connectedness of aquifers as well as the physical and chemical mechanisms governing water chemistry [4].

In the volcanic settings, the hydrogeological system of Mt. Ciremai, West Java, Indonesia, has been characterized by hydrogeochemical investigation of 119 springs [5]. A cluster analysis of 14 factors generated three groups: 1) a shallow unconfined aquifer dominated by high bicarbonate meteoric water, 2) a mixture of groundwater in unconfined aquifers and hot groundwater from deeper aquifers, and 3) groundwater flow from the deep formation. Furthermore, a hydraulic connectivity study using water chemistry factors has been conducted at the southern slope of Mt. Merapi [8], one of the world's most active volcanoes. The research findings indicate that there are three groups of springs: 1) a group of springs connected to a shallow aquifer, 2) a group of springs connected to a deeper aquifer, and 3) a group of springs that come from a porous limestone aquifer.

There have been no published hydrogeochemistry investigations of springs in the Leuwisari subdistrict and its surroundings. Based on hydrogeochemical data, this research aims to estimate hydraulic conductivity among springs in the Leuwisari subdistrict and its surrounding. This research demonstrates the use of hydrogeochemistry data so that it may serve as the basis for the management and development of springs in the study region.

2. STUDY AREA

The study area is located on the southern foot slope of Galunggung Volcano in the Tasikmalaya Regency (see Figure 1). Galunggung is a stratovolcano with an elevation of 2,168 m amsl [9], situated in Garut (west flank) and Tasikmalaya Regency (east flank). Numerous investigations, including geology and volcanology, have been done in the region. Never any hydrogeology research has been conducted.

There are records of the Galunggung Volcano erupting in 1822, 1894, 1918, and 1982 [10]. These eruptions produced new deposits on the ruins of previous deposits formed by eruptions before 1822 [11]. Volcanic deposits resulting from quaternary volcanism are spring-bearing aquifers [12] and productive aquifers [5].

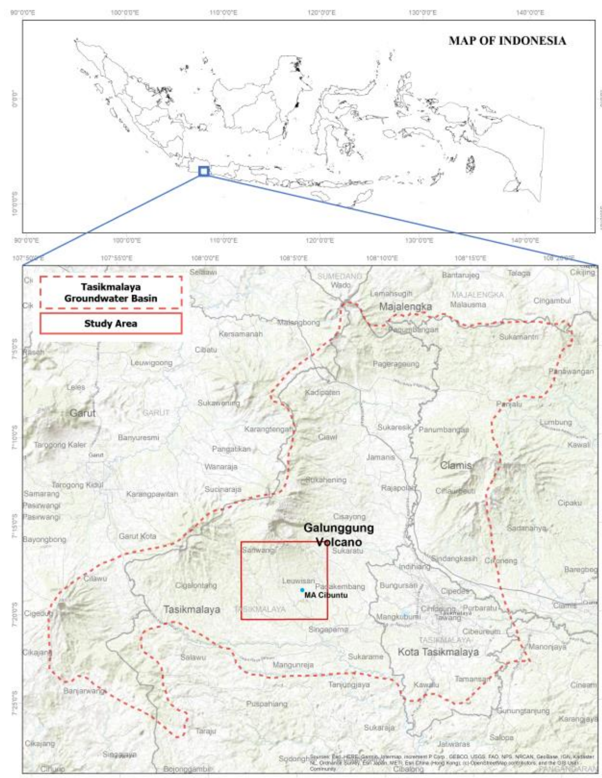

Figure 1 A red dashed line shows the Tasikmalaya groundwater basin, and the study area is indicated by a red rectangle.

Figure 2 of regional geological maps [13] indicates that a rock formation in the Cibuntu Spring is younger Volcanics (Qvg1) composed of volcanic breccia, lahars, and andesitic to basaltic tuffs from Galunggung. Qvg1 is bordered by Galunggung Volcanic Breccia (Qvb4), which has blocks of andesitic lava creating solitary blocks, and Older Volcanics (Qtvk), which contains volcanic breccia, flow breccia, tuff, and andesitic lava from Mt. Kukus.

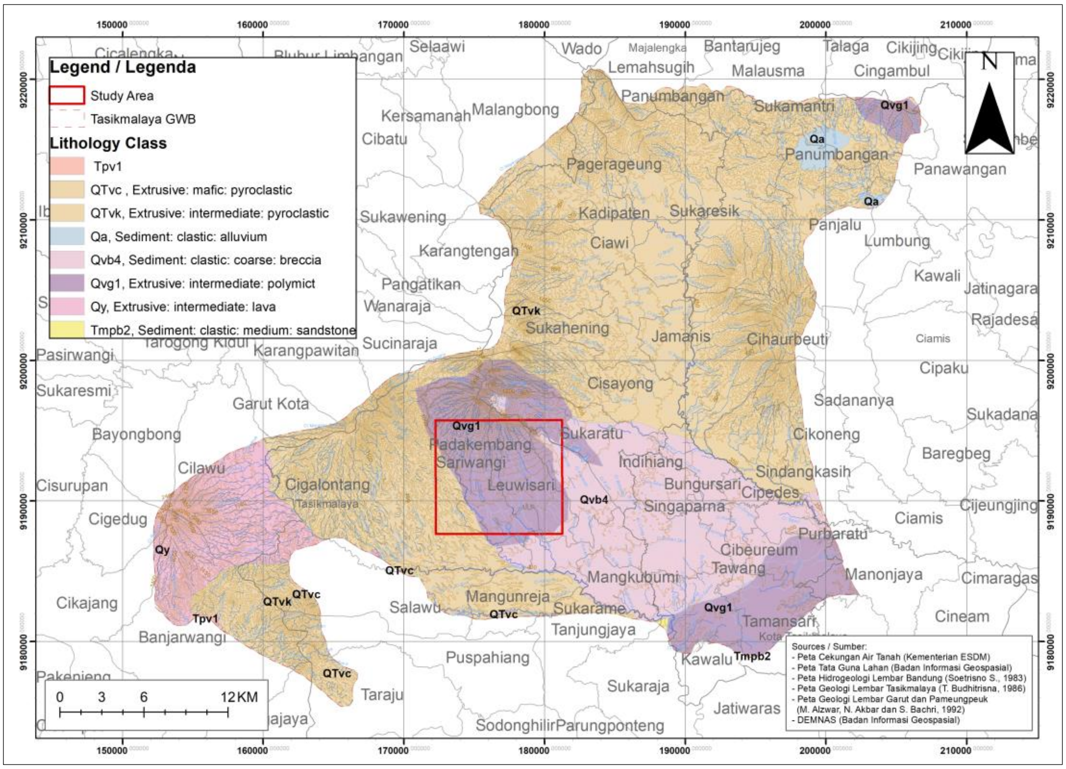

Figure 2 Regional geological map of the study area.

According to the Bandung hydrogeologic map [14], the study area comprised of young volcanic deposits consisting of tuffs, lahars, breccias, and andesitic to basaltic lavas. These rocks have a moderate to high rate of permeability. The aquifers have modest production, widespread dispersion, and radically varied transmissivities. Shallow groundwater flows from the northwest to the southeast. Several springs in the area of study are exploited for domestic water supply and agricultural irrigation.

Temperatures range from 17.4°C to 33°C, and annual precipitation averages between 3,500 mm and 5,000 mm. The months with the least precipitation are June, July, and August. The monthly average humidity is 84.1 percent, with minimum and maximum values of 67.1 and 92.5 percent, respectively [2].

Most of the study area comprises irrigated rice fields, particularly on the northern and eastern foot slopes of Galunggung. Three significant drainage patterns exist: Citanduy to the east, Ciwulan to the south, and Cimanuk to the north.

3. METHOD

In this study, regional geological maps at a scale of 1:100,000 and regional hydrogeological maps at a scale of 1:250,000 were used. The hydrochemistry and geological characteristics were analyzed to discover which sets of geological characteristics influence the groundwater system.

In order to achieve the research aims, from April to May 2022, 8 springs in the study region were subjected to in-depth field investigations. Table 1 and Figure 8 depict the locations of springs observed. Eight observed springs arise from younger volcanic composed of volcanic breccia, lahars, and andesitic to basaltic tuffs from Galunggung. During the field observation, the physicochemical parameters of water, such as water temperature, pH, total dissolved solids (TDS), and electric conductivity (EC), were measured using portable equipment HANNA HI9811-5.

Table 1. Observed spring in the study area.

No.	Spring Name	UTM WGS 1984 49S X (m)	UTM WGS 1984 49S Y (m)	Altitude (m AMSL)
1	Cibuntu	178646	9190709	554
2	Cipondok	174190	9191208	632
3	Citerewes	178385	9190469	536
4	Kalipicung	177858	9191796	638
5	Manggung	177602	9191732	629
6	Cijambe	176278	9188341	508
7	Cipiit	176176	9191609	652
8	Cipager	175324	9193399	857

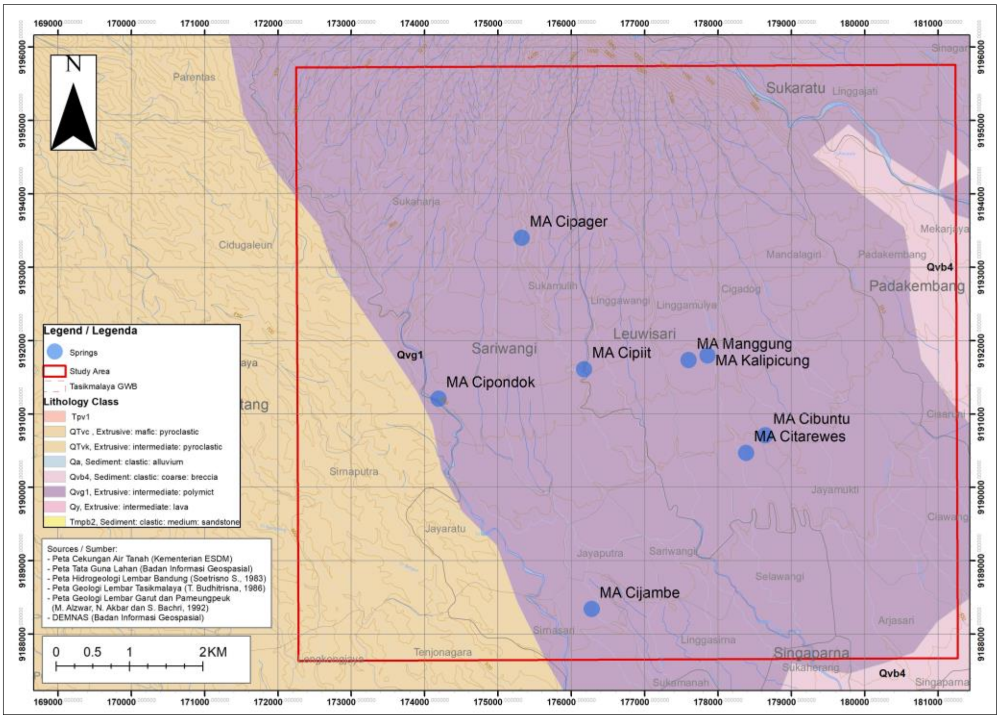

Figure 3 Location of the observed springs in the study area.

During the field observation period, spring water samples were collected once during the rainy season. 500 mL HDPE bottles were used to sample the spring water for laboratory tests. The ions composition of spring water samples was analyzed using the ion chromatography method and the Metrohm 883 Basic IC Plus at the Laboratorium Teknologi Proses Radiasi, Badan Riset dan Inovasi Nasional, Jakarta, Indonesia. The springwater samples were examined for significant ions such as Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, and Cl^- (see Table 1).

The reliability of a geochemical analysis may be determined by comparing the total number of negative and positive charges in the solution [15], [16]. The charge balance error (CBE) is then calculated by comparing the difference between the sums of all major cations (Σcat) and anions (Σan) to the total of all major ions.

$$CBE(\%) = \frac{\sum cat - \sum an}{\sum cat + \sum an} \times 100 \quad (1)$$

Acceptable charge balance errors are fewer than 5% [15], [16]. When errors exceed 5%, a major contributing species may have been ignored or mismeasured.

The types of springwater were classified using the Kurlov formula and Back 1966 hydrochemical facies. Chemical composition analysis, fingerprint diagrams, and Piper diagrams were used to study the hydraulic connectivity of springs in the study area.

4. RESULTS AND DISCUSSION

The field measurements and laboratory studies, comprising physicochemical and geochemical data of spring water samples, are listed in Table 1. Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-} are the major ion species in groundwater. These ions serve as a dissolved representation of the aquifer's lithology and chemical process and may also be utilized to estimate the hydraulic connectivity, particularly conservative ions such as Cl^- [15].

Before further analyses, chemical test results were validated using the CBE equation. We determined a 5% error value as an allowable limit. Samples with a CBE value of more than 5% will be re-tested, while samples with a CBE value of less than 5% will be analyzed. The CBE values of springwaters sampled in this study ranged from -1.47% to 4.71%.

Table 2. Physicochemical and hydrogeochemical composition of observed springwater in the study area collected in March 2022.

No.	Spring Name	Altitude (m AMSL)	Physicochemical Properties				Cations (mg/L)				Anions (mg/L)			CBE (%)
			T (C)	pH	TDS (ppm)	EC (µS/cm)	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	
1	Cibuntu	554	26	6.8	90	190	7.7	1.5	8.7	20.5	1.7	16.3	93.6	4.71
2	Cipondok	632	22	6.9	87	180	6.3	1.6	6.4	23.9	1.4	25.8	82.0	2.85
3	Citerewes	536	24	6.7	80	163	6.8	1.6	7.0	18.8	1.9	18.6	78.2	3.57
4	Kalipicung	638	23	6.5	70	150	6.3	1.7	4.9	14.7	1.2	15.0	70.2	-1.47
5	Manggung	629	22	6.7	73	160	7.1	1.9	5.3	18.1	1.3	20.5	73.9	0.62
6	Cijambe	508	26	7.0	133	280	5.3	0.2	12.2	22.8	1.6	10.4	129.2	-0.05
7	Cipiit	652	24	7.2	120	250	7.2	2.0	7.3	24.1	1.2	23.3	90.0	4.15
8	Cipager	857	22	7.1	70	150	6.6	2.0	5.8	23.4	1.1	17.8	85.9	4.55

Hydrochemical facies refers to the diagnostic chemical characteristics of groundwater solutions in hydrologic systems [7]. Kurlov formula is a practical approach for determining the fundamental chemical composition of water [17]. In defining the type of water, only constituents comprising more than 25% of the total meq/l are considered. The Kurlov formula may be used to summarize water composition in a table or on a map. It helps classify and serves as a foundation for graphical approaches and further interpretation [17].

Using the wet season data of spring water and the Kurlov formula, 5 springs in the study area are classified as Ca-Mg–HCO_3 water (Cibuntu, Citerewes, Kalipicung, Cijambe and Cipiit), 2 springs as Ca-Mg–HCO_3-SO_4 water (Cipondok and Manggung) and 1 spring as Ca-HCO3 water (Cipager), see Table 3. Based on the classification of hydrochemical facies [7], all anion facies is bicarbonate-chloride-sulfate, and mostly cation facies is calcium-sodium, with Cijambe being the lone exception. These water facies corresponds to the lithology of the aquifer. Ca, Mg, and HCO3 are the predominant ions in groundwater samples, which is consistent with the composition of groundwater in basalts. Basalts are composed mostly of plagioclase and ferromagnesian minerals rich in Ca and Mg that quickly weather [18]. Instead, the bicarbonate anion may be derived from atmospheric and soil CO2 [18]. Nevertheless, a low TDS and Ca concentration (100 mg/L) show that rainfall is still a significant contribution to the chemical composition of the water [19].

The Mg and HCO_3 concentrations rise from the northwest to the southeast of the research region, and this distribution results from differences in geology and an increase in residency times. Human activities may also affect it, but local concentrations may be elevated due to sources such as animal waste and fertilizer. Nevertheless, the insignificant concentrations of Cl in the water's chemical composition suggest that anthropogenic activities have little contaminated the springwater in the research region.

Groundwater samples indicate a constant geochemical change as their distance from the volcano increases. This spatial evolution of water chemistry implies that Cibuntu, Cipondok, Citerewes, Kalipicung, Manggung, Cipiit, and Cipager are part of the same hydrogeological system, with groundwater aging as it flows southeastward.

Figure 4 shows a fingerprint diagram or Schoeller diagram of the chemical composition data of springwater. In this graphic, each spring water is represented by a line that visually depicts the relative abundance pattern of dissolved ions (the form of each line) and the relative salinity (the position of the line at the upper or lower part of the diagram). Each line represents the compositional imprint of a water sample, and comparable patterns indicate roughly similar water types and sources [15]. The Schoeller diagram is superior to other visualization methods in that it can display multiple analyzes on the same plot and compare the hydrochemical properties of different samples [18].

Chemical data plotted on a fingerprint diagram reveals that spring water in the study area may be categorized into some categories. Figure 4 clearly depicts the two groups of spring water in the research region, displaying two unique line patterns, with the green line indicating the water from Cijambe spring (Group 1). The other lines show line patterns of spring water from Cibuntu, Cipondok, Citerewes, Kalipicung, Manggung, Cipiit and Cipager (Group 2). Group 2 consists of seven springs with similar chemical compositions of Ca–Mg–HCO3 and electrical conductivity range between 150 to 250 µS/cm. Group 1 consists of only one spring Cijambe which contains a similar chemical composition to Group 1 but has a significantly higher bicarbonate concentration with an EC value of about 280 µS/cm

Table 3. Kurlov Classification of observed springwater in the study area.

No.	Spring Name	Altitude (m AMSL)	Lithology	Cations (%meq/L)			Anions (%meq/L)			Kurlov Classification	Hydrochemical Facies [7]	
				Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	$HCO3^{-}$	SO_4^{2-}	Cl^{-}		Cation Facies	Anion Facies
1	Cibuntu	554	Lahar deposits	48.45	33.90	17.64	79.84	17.66	2.50	Ca-Mg-HCO_3	Calcium-Sodium	Bicarbonate-chloride-sulphate
2	Cipondok	632	Andesitic lava	58.66	25.89	15.45	69.97	27.97	2.06	Ca-Mg-HCO_3-SO_4	Calcium-Sodium	Bicarbonate-chloride-sulphate
3	Citerewes	536	Volcanic breccia	50.71	31.13	18.16	74.41	22.48	3.11	Ca-Mg-HCO_3	Calcium-Sodium	Bicarbonate-chloride-sulphate
4	Kalipicung	638	Volcanic breccia	50.48	27.74	21.79	76.87	20.87	2.26	Ca-Mg-HCO_3	Calcium-Sodium	Bicarbonate-chloride-sulphate
5	Manggung	629	Volcanic breccia	53.27	25.71	21.02	72.32	25.49	2.19	Ca-Mg-HCO_3-SO_4	Calcium-Sodium	Bicarbonate-chloride-sulphate
6	Cijambe	508	Pyroclastic deposits	47.87	42.22	9.91	89.00	9.10	1.90	Ca-Mg-HCO_3	Calcium-Magnesium	Bicarbonate-chloride-sulphate
7	Cipiit	652	tuff-breccia	55.51	27.72	16.77	73.97	24.33	1.70	Ca-Mg-HCO_3	Calcium-Sodium	Bicarbonate-chloride-sulphate
8	Cipager	857	Andesitic lava	58.91	24.07	17.01	77.80	20.48	1.71	Ca-HCO_3	Calcium-Sodium	Bicarbonate-chloride-sulphate

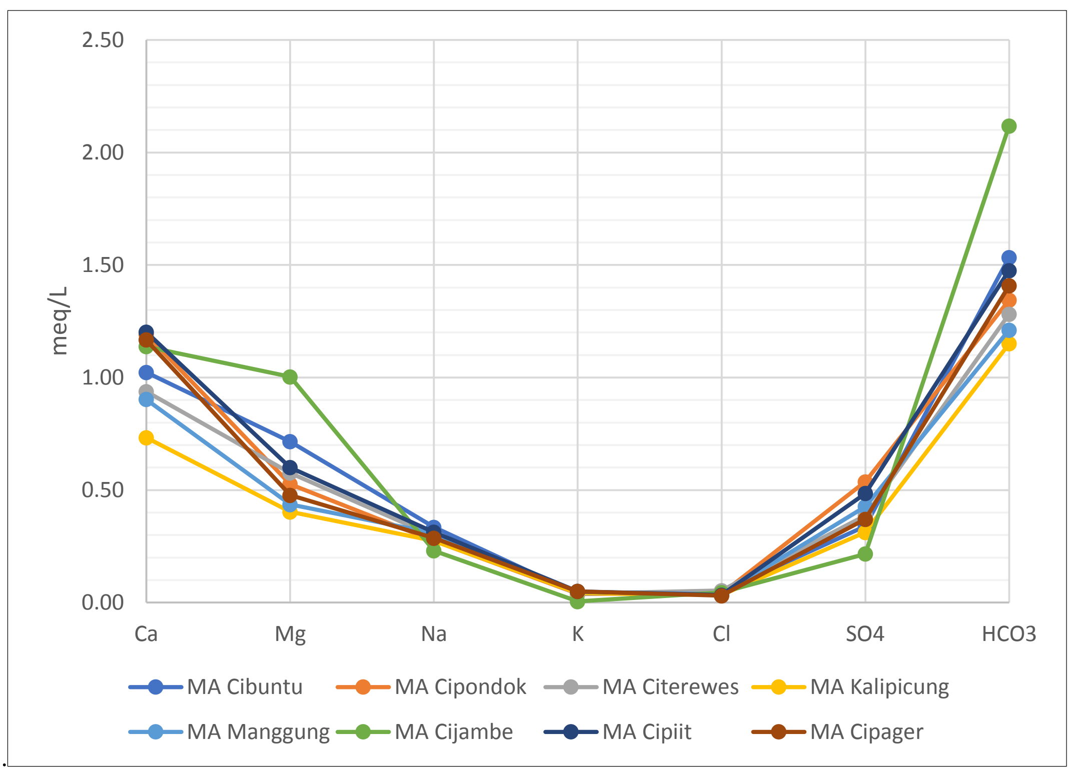

Figure 4 Fingerprint diagram of hydrogeochemical data of springwater in the study area.

The concentrations of groundwater chemical characteristics may be displayed in x–y diagrams or composition diagrams using meq/l. Complementing the fingerprint diagram, the composition diagram offers a convenient approach to graphically representing vast quantities of data [12]. In addition, the composition diagram of the water chemistry reveals the emergence of two separate compositional water groups. Figure 5 suggests that: 1) there are two clusters of water that may represent different aquifer systems or water sources, and 2) Cijambe spring is supplied by water with considerably more fantastic Mg and HCO_3 concentrations than the other springs.

The trilinear Piper plot is one of the most well-known diagrams for illustrating the primary geochemical components of waters [20]. There are two basic triangular plots and one diamond in the diagram: the triangles represent the molar percentages of the three most abundant anions, HCO^3, SO_4^2, and Cl^-, and the three most abundant cations, Na^+(plus K^+), Ca^{2+}, and Mg^{2+} (Figure 19).

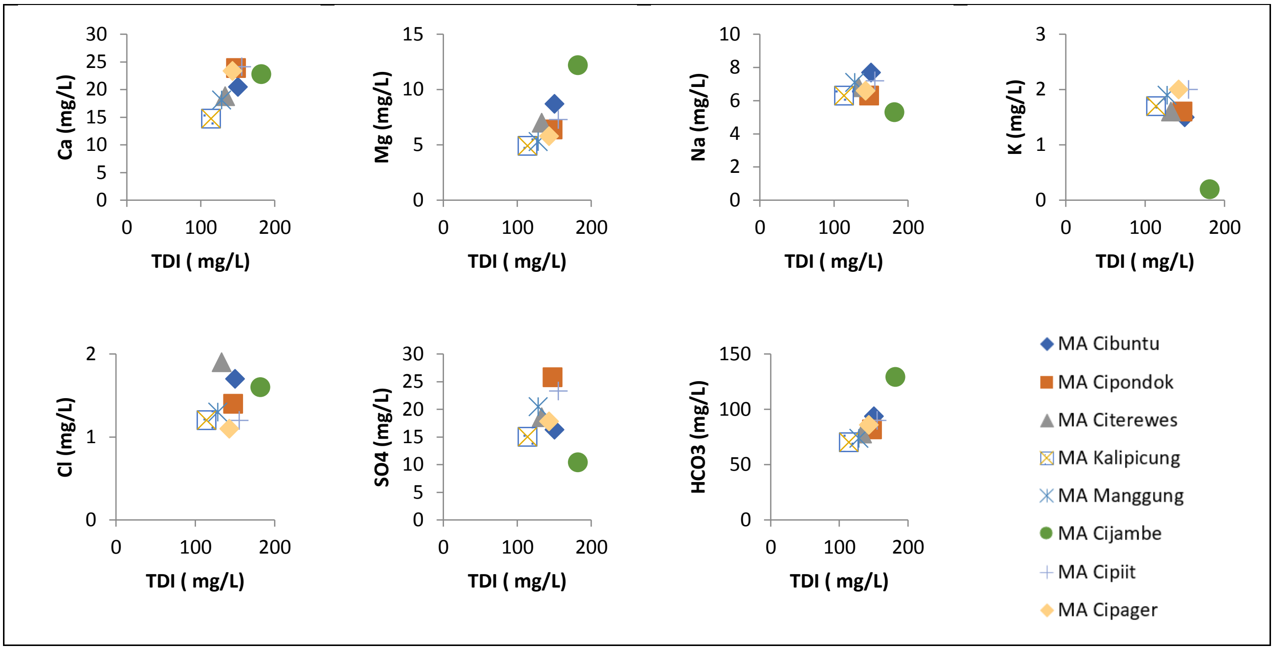

Figure 5. Compositional diagram of hydrogeochemical data of spring water in the study area.

The geochemical facies may be determined by extending two points along lines parallel to the diagram's sides and then crossing these lines in the diamond's quarter. Based on this, it is believed that Ca-Mg-HCO_3 water is the only groundwater facies in the research region. The Ca-Mg–HCO_3 facies is typical bicarbonate groundwater that originated from minerals near the surface [16].

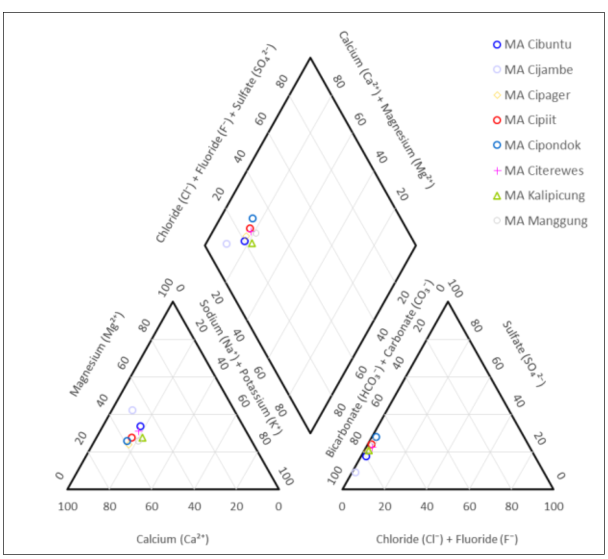

Figure 6. Piper diagram of hydrogeochemical data of springwater in the study area.

According to fingerprint, compositional, and Piper diagram evaluation, at least two aquifer systems are feeding those two groups of springs: a shallow aquifer system affected by local rainwater recharge and a deeper aquifer system.

5. CONCLUSION

Based on the information presented in the preceding section, several conclusions about this study may be drawn. Considering the geology and hydrogeology of the region, the following conclusions may be made:

1) The dominant spring water type on the southern foot slope of Galunggung Volcano is Ca-Mg–HCO_3 water;

2) The groundwater facies in the study area can be divided into two distinct groups, with Group 1 consisting of seven springs with similar chemical compositions of Ca–Mg–HCO_3 and electrical conductivity ranges between 150 and 250 (µS/cm), Group 2 consisting of only one spring, Cijambe, with similar chemical composition to Group 1 but significantly higher bicarbonate concentration.

3) Group 2 is hydraulically connected to the shallow aquifer system, whereas Group 1 originates from the deeper aquifer system. Both groups may originate from local precipitation and are influenced by a weathered basalt. This investigation of the hydraulic conductivity of the spring might very well

be used as a guide for identifying the spring conservation zone in order to protect the sustainability of springs in the study area.

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REFERENCES

[1] BPS Kabupaten Tasikmalaya (BPS-Statistics of Tasikmalaya Regency), Kabupaten Tasikmalaya dalam Angka (Tasikmalaya Regency in Figures) 2022, Kabupaten Tasikmalaya, 2022.

[2] BPS Kota Tasikmalaya (BPS-Statistics of Tasikmalaya Municipality), Kota Tasikmalaya dalam Angka (Tasikmalaya Municipality in Figures) 2022, Kota Tasikmalaya, 2022.

[3] Pemerintah Kabupaten Tasikmalaya, Pemutakhiran Dokumen Rencana Induk Pengembangan Sistem Penyediaan Air Minum Kabupaten Tasikmalaya (Updating the Master Plan Document for the Development of Drinking Water Supply System for Tasikmalaya Regency), Kabupaten Tasikmalaya, 2019.

[4] G. Thyne, C. Güler, and E. Poeter, Sequential analysis of hydrochemical data for watershed characterization, Ground Water, vol. 42, no. 5, 2004, pp. 711–723, doi: 10.1111/j.1745-6584.2004.tb02725.x.

[5] D. E. Irawan, D. J. Puradimaja, S. Notosiswoyo, and P. Soemintadiredja, Hydrogeochemistry of volcanic hydrogeology based on cluster analysis of Mount Ciremai, West Java, Indonesia, J. Hydrol., vol. 376, no. 1–2, 2009, pp. 221–234, doi: 10.1016/j.jhydrol.2009.07.033.

[6] W. B. White, Springwater Geochemistry, in Groundwater Hydrology of Springs, 1st Editio., Butterworth-Heinemann: Elsevier Inc., 2010, pp. 231–268.

[7] William Black, Hydrochemical facies and ground-water flow patterns in Northern part of Atlantic Coastal Plain. Geological Survey Professional Paper 498-A. US Government Printing Office, Hydrol. Aquifer Syst., 1966 p. Page 1-50.

[8] J. Boulom, D. P. Eka Putra, and W. Wilopo, Chemical Composition and Hydraulic Connectivity of Springs in the Southern Slope of Merapi Volcano, J. Appl. Geol., vol. 6, no. 1, 2015, pp. 1–11, doi: 10.22146/jag.7212.

[9] Pusat Vulkanologi dan Mitigasi Bencana Geologi, Data Dasar Gunungapi Indonesia - G. Galunggung (Volcano Database of Indonesia - Galunggung). [Online]. Available: https://vsi.esdm.go.id/index.php/gunungapi/data-dasar-gunungapi/523-g-galunggung. [Accessed: 10-May-2022].

[10] S. Bronto, Volcanic geology of Galunggung, West Java, Indonesia, 1989.

[11] B. Mulyanto, Morphological, Physical, and Chemical Characteristic of Some Volcanic Soils of Mt. Galunggung, J. Ilmu Tanah dan Lingkung., vol. 2, no. 1, 1999 pp. 25–32.

[12] O. Setiawan, Zoning of Spring Conservation Areas Based on Morphology and Surface Material on the Southern Slope of Rinjani Volcano, Lombok, Universitas Gadjah Mada, 2019.

[13] Budhitrisna, Peta Geologi Lembar Tasikmalaya Skala 1:100.000 (Geological Map Sheet Tasikmalaya Scale 1:100.000). Pusat Penelitian dan Pengembangan Geologi, Bandung, 1986.

[14] Soetrisno, Peta Hidrogeologi Indonesia Lembar Bandung Skala 1:250.000 (Hidrogeological Map of Indonesia Sheet Bandung Scale 1:250.000). Direktorat Geologi Tata Lingkungan, Bandung, 1983.

[15] E. Mazor, Chemical and Isotopic Groundwater Hydrology, Third Edit. New York: Marcel Dekker, 2004.

[16] I. Clark, Groundwater geochemistry and isotopes. 2015.

[17] A. Zaporozec, Graphical Interpretation of Water Quality Data, Groundwater, vol. 10, 1972, pp. 32–43, doi: 10.1111/j.1745-6584.1972.tb02912.x.

[18] B. B. S. Singhal and R. P. Gupta, Applied Hydrogeology of Fractured Rocks, vol. 1. 2019.

[19] R. A. T. Listyani and D. Isnawana, Geochemical of Karst Water in the Western Part of Gunungkidul District Area, Int. J. Adv. Sci. Eng. Inf. Technol., vol. 11, no. 3, 2021, pp. 955–961, doi: 10.18517/ijaseit.11.3.14421.

[20] A. M. Piper, A Graphic Procedure in The Geochemical Interpretation of Water-Analyses, Am. Geophys. Union, 1944, pp. 914–928, doi: 10.1029/TR025i006p00914.

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