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Research article

Hydrogeochemical characteristics of groundwater in Baleendah - Soreang, South Bandung, West Java Province

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ABSTRACT

The Baleendah – Soreang area is part of the southern part of the Bandung Soreang Groundwater Basin, constructed by volcanic activity. Regional development in the Baleendah – Soreang area can decrease groundwater quality, influenced by natural and anthropogenic factors. Groundwater hydrogeochemical analysis is important in environmental management studies. This study aims to determine groundwater's physical properties and hydrogeochemical facies in this area. The groundwater hydrochemistry analysis, determined by analysis of Stiff diagrams and Piper diagrams, shows that the groundwater in the area is classified as freshwater and has intermediate groundwater flow. In addition, the groundwater quality is affected by some anthropogenic activities.

INTRODUCTION

Hydrogeochemistry is the science that discusses the composition and characteristics of groundwater (Tikhomirov, 2016). In broader terms, this definition includes the composition, physical, chemical, biological, and hydrochemical characteristics of groundwater. The scope of hydrogeochemistry itself includes defining the timing and sources of groundwater recharge, estimating groundwater's period in aquifers, explaining how groundwater experiences mixing and interacts with rocks, as well as evaluating the types of geochemical processes that occur during the flow of groundwater within the aquifer. Nonetheless, due to various limitations, very few hydrogeochemical studies have thoroughly discussed this scope.

Hydrogeochemical analysis in environmental management studies is fundamental (Šráček and Zeman, 2004) to find out the processes that occur in groundwater, rock types that dominantly affect water quality, and pollution affecting groundwater quality (Hem, 1985; Gilli et al., 2012; Hiscock and Bense, 2014). This will undoubtedly help plan the management of groundwater resources in the future.

In many parts of the world, volcanic aquifers are crucial—and occasionally the only—sources of groundwater (Hendarmawan and Satrio, 2011). They are kept in volcanic rocks, which are thought to cover a smaller area of the continental crust than other types of rocks. Only 6.8 to 8% of all the earth's rock types are exposed to volcanic rock on continents (Blatt and Jones, 1975; Meybeck, 1987; Suchet et al., 2003). The properties of the groundwater in volcanic areas have very complicated and complex conditions, so there is a need for a comprehensive and detailed approach to reveal the phenomenon of the development of land use according to its function (Hadian et al., 2016). Population development around volcanic areas will increase water consumption (Satrio et al., 2016). Excessive groundwater withdrawal will cause environmental changes such as reduced groundwater reserves, drought in the dry season, and groundwater contamination. Over-exploit groundwater will decrease the groundwater level and pressure (Hadian et al., 2013).

The volcanic area of South Bandung is part of the Citarum upstream watershed, which is located in Bandung Regency. The potential for abundant water resources in this region is the main support for fulfilling raw water for Bandung City and Bandung Regency (Resubun et al., 2018). The expansion of built-up land for settlements in the South Bandung area is feared to impact groundwater conservation areas, especially in the Baleendah – Soreang area. The Baleendah – Soreang area is utilized for airports, plantation forests, settlements, dry land farming, dry land farming mixed with shrubs, paddy fields, and open land (Ministry of Environment and Forestry, 2021). This study aims to evaluate the hydrochemical processes in groundwater by identifying the physical properties and analyzing the facies of groundwater in several land covers in the South Bandung area, specifically in the Baleendah – Soreang volcanic area.

GEOLOGICAL SECTION

The research area is located at 107°28'E–107°41'E and 6°58'S–7° 5'S. The geological conditions of the study area (Figure 1) are composed of several rock units, i.e., Lake Deposits (Qd) with tuffaceous claystone, tuffaceous siltstone, and fine tuffaceous sandstone to coarse-gravel Holocene age lithology. The Malabar-Tilu (Qmt) volcanic rock covers tuff and lava breccias lithology.

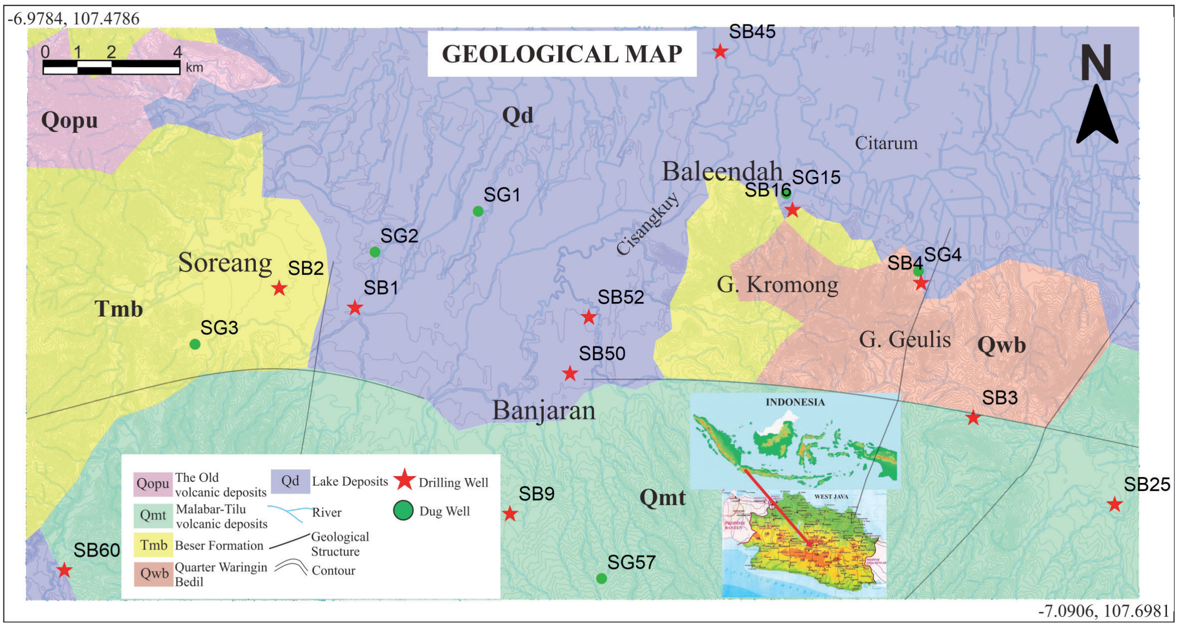

Figure 1. Research Locations on the Geological Map of the Baleendah - Soreang Region (Modification from Alzwar et al., 1992)

The lava breccias lithology contains small amounts of pumice and lava. Old Malabar (Qwb) Waringin-Bedil Andesite covers breccia and tuff lithology. The breccia lithology contains of pyroxene andesite and hornblende. The rock unit is from the Beser Formation (Tmb) with tuffaceous breccia and lavas lithology, composed of late Miocene andesite to basalt. Old volcanic deposits (Qopu) of Pleistocene age have not been decomposed, consisting of fine-coarse crystalline tuff, dacite, tuff breccias containing old pumice deposits and andesitic lava (Alzwar et al., 1992).

METHOD

This research on geology and hydrogeology of the Baleendah – Soreang area was carried out by mapping the research location along with the sampling points using ArcMap 10.8. Seventeen groundwater samples were analyzed, nine physical and chemical data samples were obtained from a former study by Maria et al. (2021), and eight samples were obtained directly from the field. The field investigation was carried out in the rainy season in June 2022. Samples were taken from dug and drilled wells at several elevations (Figure 1) for subsequent laboratory analysis. Geological research is carried out by observing rocks to determine the surrounding geological conditions. The geological and land use data were used to interpret their effect on variations of groundwater hydrogeological facies (He et al., 2020).

Physical analysis of groundwater was carried out by directly measuring pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS). Chemical analysis of groundwater was carried out by analyzing the major elements of groundwater in the laboratory. The cations elements analyzed included Calcium (Ca^{2+}), Sodium (Na^{+}), Magnesium (Mg^{2+}), and Potassium (K^{+}) were analyzed using the Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) method. Furthermore, the Chloride anion (Cl^{-}) was analyzed by the argentometric method, the bicarbonate anion (HCO_3^{-}) was analyzed by the titration method, and the sulfate anion (SO_4^{2-}) was analyzed by the turbidimetric method.

Analytical laboratories usually consider a Charge Balance Error (CBE) of <±5% to be acceptable (Freeze and Cherry, 1979). A CBE value close to zero indicates that the conditions of cations and anions in groundwater are balanced or nearly the same. The CBE is calculated by Equation 1.

$$\text{CBE (\%)} = \frac{(\Sigma \text{ cations - } \Sigma \text{ anions})}{(\Sigma \text{ cations + } \Sigma \text{ anions})} \times 100 \qquad \text{Equation 1}$$

The units of the results from the analysis of the chemical elements of groundwater are converted from mg/L to meq/L (Hem, 1985).

Determination of the hydrogeochemical facies is one method used to identify the chemical origin of groundwater (Chidambaram et al., 2013). Stiff and Piper diagrams were used to determine groundwater's hydrogeochemical type or facies (Krishnaraj et al., 2011). In this study, Piper and Stiff diagrams were made using Rockworks 16.

This study used statistical analysis of Pearson's correlation to assess the correlation between various hydrochemical parameters (Nwankwoala et al., 2014, Sreedevi et al., 2018). According to the correlation coefficient (r), the degree of relevance can be divided into three levels: strong ($r \geq 0.7$), moderate ($0.7 > r > 0.5$), and weak ($r \leq 0.5$) (Emenike et al., 2018). In this study, Pearson correlation was calculated using Microsoft Office Excel 2019.

RESULT AND DISCUSSION

The Physical and Chemical Characteristics of Groundwater

The direct physical properties measurement results from dug and drilled wells in Table 1 show heterogeneous characteristics. The EC value ranges from 50 to 890 µS/cm, TDS from 10 to 518 mg/L, and pH from 6.1 to 8.6 (Table 1). Based on data on the range of TDS values (0-1000 mg/L), the study area is included in the Fresh Water category (Mandel et al., 1981).

Table 1. Physical Characteristics of Groundwater in the South Bandung Region

Type of sample	Elevation (m)	pH	EC (µS/cm)	TDS (mg/L)
SB4	707	8.2	840	310
SG4	720	8	800	390
SB3	855	8	80	30
SB1	700	8.6	890	330
SB2	749	8.5	70	30
SG2	703	8.1	110	50
SG1	692	8.6	140	60
SG3	734	8	450	220
SB9	809	7.4	100	126
SG15	700	7.2	700	518
SB16	701	6.7	230	244
SB25	810	6.4	70	28
SB45	689	7.7	440	280
SB50	706	7.7	230	172
SB52	696	7.6	400	308
SG57	965	6.1	50	130
SB60	1059	7.5	170	266

Table 2 presents the major cation and anion concentration analysis results for seventeen samples. Furthermore, the CBE calculation shows that four samples (SG4, SB3, SB1, and SB2) had a CBE value of more than ±5%. Therefore, those four hydrochemical data are not used in the analysis.

Table 2. Data on the Ion Concentration of the Major Elements of Groundwater for the South Bandung Region in mg/L

Sample ID	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+} (mg/L)	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CBE (%)
SB4	25.7	9.7	16.5	16.9	24.2	16.3	128.9	1.58
SG4	*30.0*	*11.8*	*36.3*	*11.9*	*65.2*	19.8	81.4	9.62
SB3	12.3	2.7	4.8	3.0	3.7	4.6	48.5	5.90
SB1	26.6	8.7	26.3	20.0	37.6	23.0	161.8	*-6.31*
SB2	*24.1*	*6.3*	*17.2*	*15.7*	*31.1*	*19.9*	*135.0*	*-9.83*
SG2	13.3	5.0	13.6	6.2	13.2	28.8	55.7	-1.60
SG1	32.2	12.6	43.0	45.0	40.2	22.5	245.3	0.37
SG3	17.8	2.6	13.5	3.4	14.5	9.1	77.3	-2.50
SB9	7.7	3.9	10.1	5.0	6.9	6.4	63.2	-3.47
SG15	66.5	16.2	36.4	30.9	78.5	48.0	216.7	1.88
SB16	28.4	4.4	15.0	1.5	20.7	9.8	97.5	1.73
SB25	5.8	1.2	7.7	0.6	9.4	8.2	22.3	-4.09
SB45	36.1	16.6	25.4	6.2	16.5	4.7	228.3	1.43
SB50	15.1	6.1	25.4	3.4	20.7	4.9	103.3	1.41
SB52	20.6	7.9	32.9	2.8	53.8	4.6	107.0	-2.85
SG57	6.4	2.7	2.6	0.5	12.4	6.1	10.5	1.40
SB60	16.6	12.4	9.1	1.4	6.9	5.0	115.4	2.01

Table 3. Pearson Correlation of Groundwater in the Baleendah - Soreang Area

	EC	TDS	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
EC	1								
TDS	0.83	1							
Na^+	0.52	0.51	1						
K^+	0.33	0.20	0.71	1					
Mg^{2+}	0.52	0.65	0.70	0.57	1				
Ca^{2+}	0.58	0.71	0.71	0.66	0.79	1			
Cl^-	0.62	0.68	0.84	0.59	0.59	0.77	1		
SO_4^{2-}	0.42	0.38	0.50	0.71	0.44	0.72	0.67	1	
HCO_3^-	0.40	0.42	0.74	0.76	0.84	0.79	0.50	0.45	1

Pearson correlations for groundwater in the Baleendah – Soreang area (Table 3) shows that EC strongly correlates with TDS. The relationship between TDS and EC is a function of the type and nature of the dissolved cations and anions in the water (Sawyer et al., 1994). TDS strongly correlates with Ca^{2+} and moderately with Na^+, Mg^{2+}, and $Cl^{-,}$ indicating that the dissolving of rock minerals influences the geochemistry of the groundwater (Agyemang, 2022). Na^+ has a strong correlation with K^+, Mg^{2+}, Ca^{2+}, Cl^-, and $HCO_3^{-,}$ which shows the possibility for ion exchange in groundwater and the possible effects of human activities on the geochemistry of groundwater, such as poor waste disposal, the use of agrochemicals, and a lack of proper sanitation around point sources (Agyemang, 2022). Mg^{2+} correlates strongly with Ca^{2+} and $HCO_3^{-,}$ which indicates that processes like rock mineral dissolution and ion exchange impact the concentrations of these parameters in groundwater. Cl^- correlates moderately with SO_4^{2} and HCO_3^- are related to anthropogenic influences such as agricultural activities (Cruz-Fuentes et al., 2014).

Geological Effect on Groundwater Facies

The groundwater facies in the study area is divided into four types, i.e., $NaHCO_{3,}$ $CaHCO_3$, CaCl, and $MgHCO_3$ facies (Figure 2 and 3). The sodium bicarbonate ($NaHCO_3$) facies that HCO_3^- and Na^+–dominant typically indicate ion–exchanged water. Under certain conditions, the generation of CO_2 at depth can produce HCO_3^- with Na^+ as the dominant ion (Chadha, 1999) and is located in areas with mountainous or hilly topography. This type of water in these facies can be found in unpolluted resident wells such as wells SG2, SG1, SB9, SB25, SB50, and SB52. Calcium bicarbonate ($CaHCO_3$) facies were found in wells SB4, SG3, SG15, SB16 and SB45. Sampling during the rainy season will affect the chemical concentration of groundwater, as indicated by the presence of many $CaHCO_3$ facies. By dissolving Ca, Mg, and Na/K from silicates (albite, pyroxene), meteoric water would produce $CaHCO_3$ and $CaMgHCO_3$ water types, which could later develop into $CaNaHCO_3$ water types due to cation exchange (Garrels and Mackenzie, 1967).

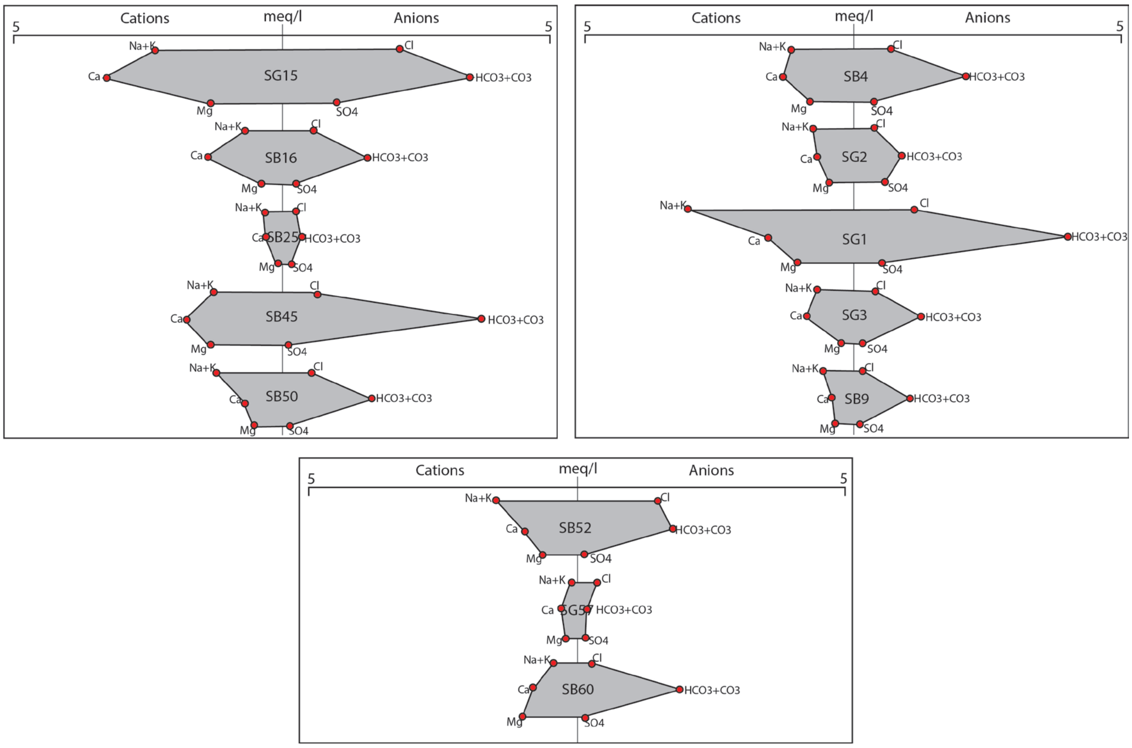

Figure 2. Stiff Diagram Showing Groundwater Facies in the Study Area

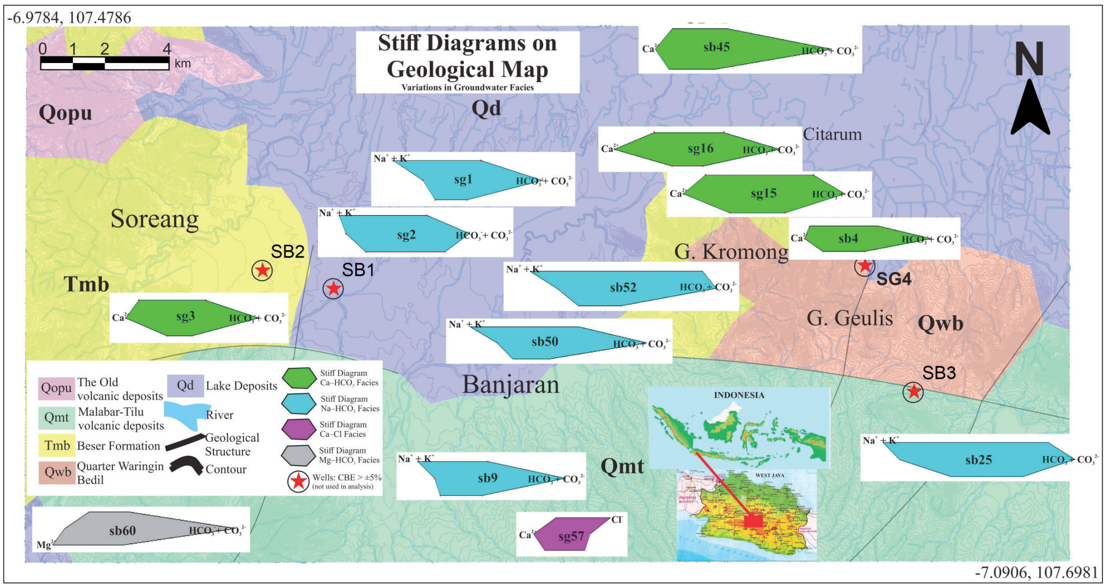

Figure 3. Stiff Diagram (scale adjusted) on Geological Map of Research Area

The interaction with volcanic rocks caused most of the Ca^{2+} content. HCO_3^- indicates that shallow groundwater has merged with groundwater during local recharge (Maria et al., 2022). Weathering of rocks affects the presence of Ca^{2+} cations, while atmospheric conditions and the amount of time water has been stored in rocks affect the bicarbonate anion (HCO_3^-) (Krishnaraj et al., 2011). Facies of calcium chloride (CaCl) are located at SG57 well. High Cl^- concentrations can result from geothermal activity contamination in volcanic areas (Maria et al., 2022). The high chloride content in the study area was caused by several factors, including anthropogenic influences. Facies of magnesium bicarbonate ($MgHCO_3$) are located at SB60 well. It is evident from the enrichment of magnesium content that these facies is affected by the mixing effect and interaction between rocks and groundwater over a relatively long period of time (Maria et al., 2022).

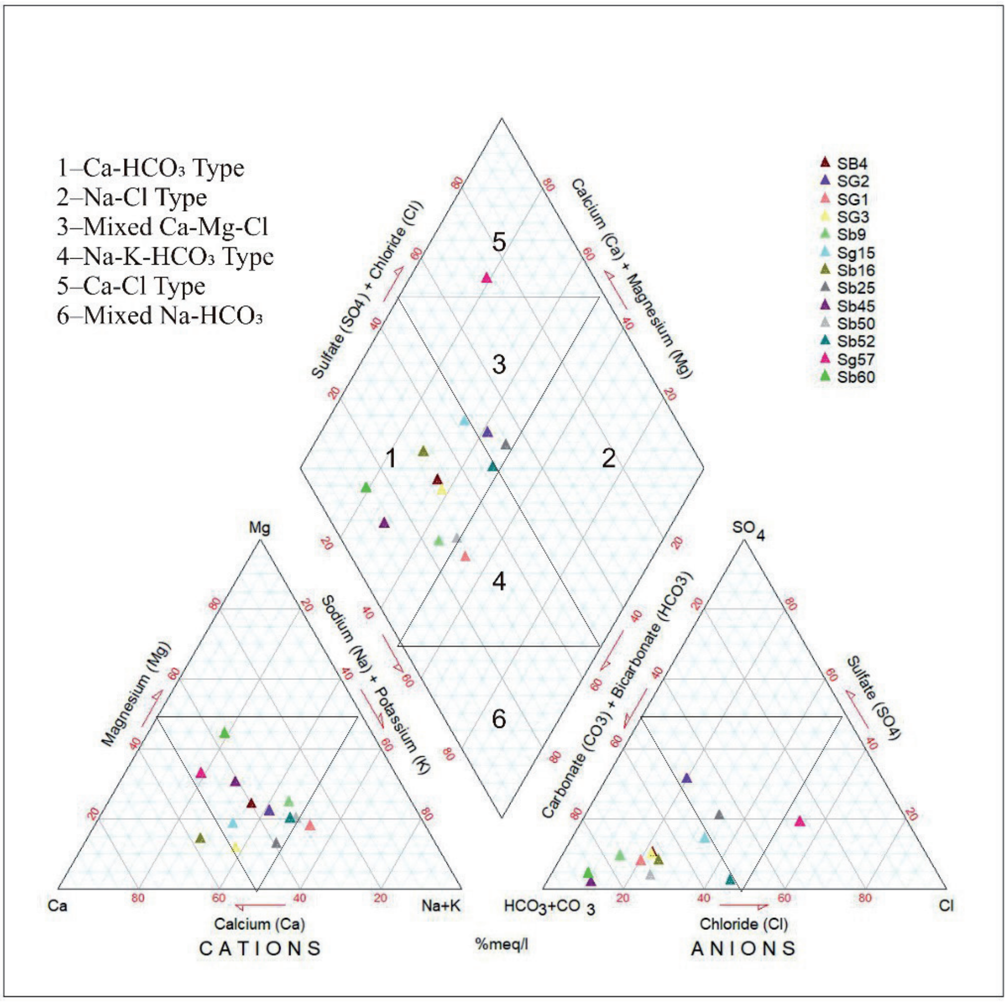

Figure 4. Piper Diagram Showing Hydrogeochemical Characteristics of Groundwater

The chemical content of groundwater is undoubtedly influenced by geochemical reactions and water mixing or contamination from the surroundings. The relationship between rock type and water composition influences groundwater change. The types of groundwater based on the Piper diagram (Figure 4) are $CaHCO_3$ in groundwater SB4, SG3, SB60, SB45, SB9, SB50, SB16, SG15, and SB52; the Mixed type CaMgCl in groundwater SG2 and SB25; $NaKHCO_3$ type in groundwater SG1; and CaCl type in groundwater SG57. The Piper trilinear diagram (Figure 4) shows the dominant hydrogeochemical facies in the study area, $CaHCO_3$.

The lithology of the Baleendah – Soreang area is composed of volcanic rock in the form of andesitic-basaltic lava. The dominance of groundwater $CaHCO_3$ types is interpreted as an interaction between water and rock (Maria et al., 2022). The $CaHCO_3$ water types show how the recharging groundwater dissolves plagioclase and other aluminosilicate minerals (pyroxene and hornblende), which is then followed by a probability of cation exchange (Ako et al., 2011). A mixed type of CaMgCl in groundwater indicates enrichment of Mg^{2+} in the interaction between groundwater and rock. The dominant composition of calcium and magnesium is produced from the weathering of silica minerals which contain lots of Ca^{2+} from basaltic andesitic volcanic rocks (Maria et al., 2021). Meanwhile, the Cl^- shows the influence of water-rock interaction and anthropogenic activity (Nigate et al., 2016). The $NaKHCO_3$ facies is groundwater in the distal area with significant anthropogenic influence. The weathering results of volcanic rocks have the mineral composition of Na-feldspar, K-feldspar, pyroxene, and olivine, producing rock minerals as a source of Na^+ and HCO_3^- (Hem, 1985).

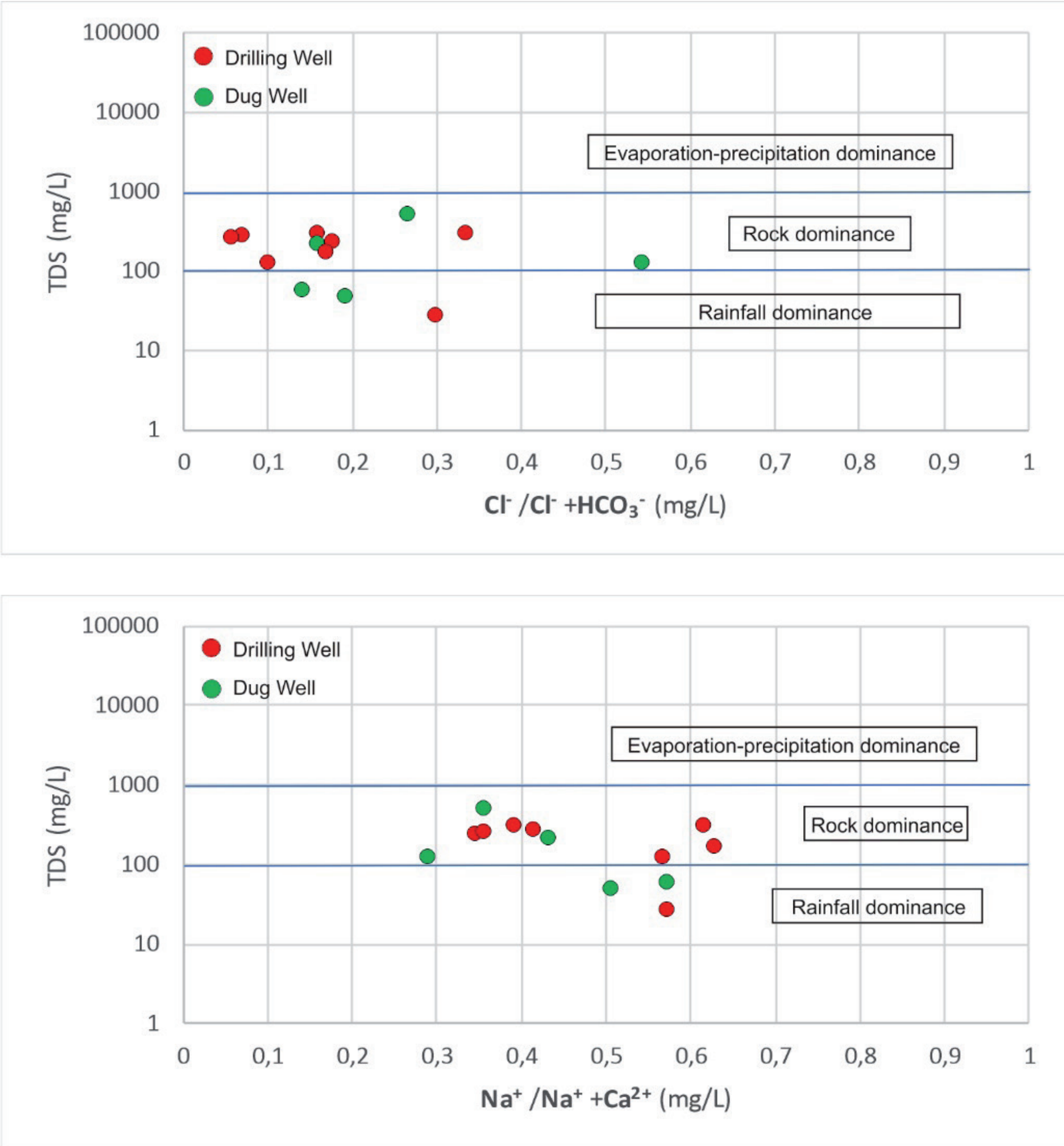

Figure 5. Gibbs diagram

The Gibbs diagram (Figure 5) shows the comparison of TDS with $Cl^-/(Cl^-+HCO_3^-)$ and TDS with $Na^+/(Na^++Ca^{2+})$ in groundwater, which are affected by rock weathering (10 samples) and the dominant influence of rainwater (3 samples). Groundwater that is affected by rock weathering includes sample SG3, SB4, SB9, SG15, SB16, SB45, SB50, SB52, SG57, and SB60. Groundwater SB50, SB52, SB45, SG15, SB16, and SB4 are in the area of lake sedimentary rock units (Qd) in the distal facies zone. Groundwater SG57, SB9 and SB60 are located in the Malabar-Tilu (Qmt) volcanic rock unit area in the medial-distal facies zone. SG3 groundwater is located in the Beser Formation (Tmb) rock units in the distal facies zone. Meanwhile, groundwater affected by rainwater includes samples SG1, SG2, and SB25; groundwater SG1 and SG2 are in the distal facies zone of the lake sedimentary rock (Qd); and groundwater SB25 is in the Malabar-Tilu (Qmt) volcanic rock unit on the proximal-medial facies zone.

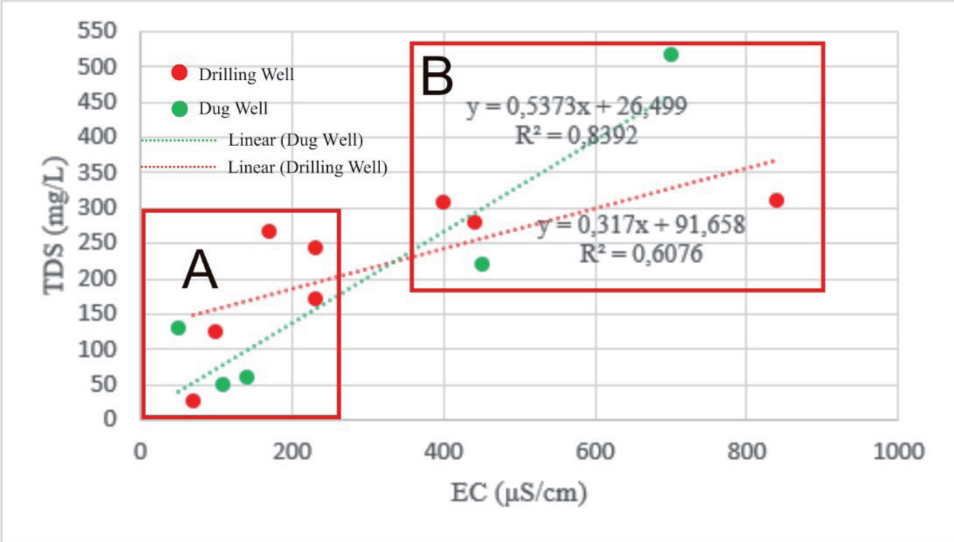

Figure 6. EC and TDS bivariate diagram in Baleendah – Soreang

Two groundwater groups are obtained from the analysis of the EC and TDS bivariate diagrams (Figure 6). Group A is groundwater with low EC and TDS values which shows that the journey of groundwater is still short and has not been in contact with rocks for a long time (Nigate et al., 2016). Most of the groundwater from group A is distributed in the Malabar-Tilu (Qmt) volcanic deposits. It has a high structural control that allows water to flow through fracture and facilitates the groundwater dilution process, thus helping rock-water interaction. While group B is groundwater with high EC and TDS values, showing a relatively long groundwater journey and rock contact (Nigate et al., 2016). Most of the groundwater from group B is distributed in the medial-distal facies with lake sedimentary tuffaceous claystone (Qd) lithology.

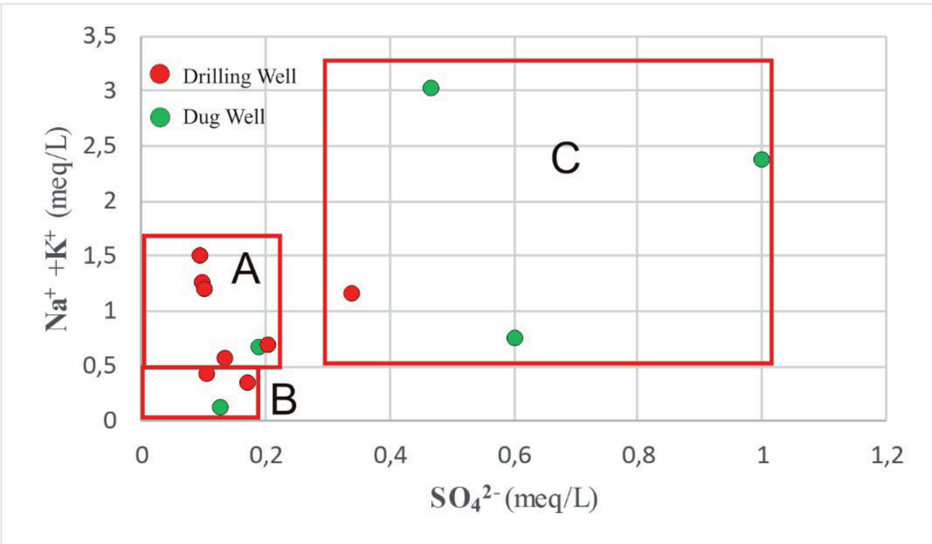

Figure 7. SO_4^{2-} and (Na^+ + K^+) Bivariate Diagram

Three groups of groundwater were obtained from the analysis of SO_4^{2-} and (Na^+ + K^+) bivariate diagrams (Figure 7). Group A is groundwater with low SO_4^{2-} and high (Na^+ + K^+) values, mostly distributed in the distal facies zone with claystone lithology of lake sedimentary (Qd). While group B is low SO_4^{2-} and (Na^+ + K^+) values, mostly distributed in the Malabar-Tilu (Qmt) volcanic rock deposits unit in the medial facies zone. Group C is high SO_4^{2-} and (Na^+ + K^+) values, mostly distributed in the distal facies of lake sedimentary (Qd). High SO42 values indicate the influence of agricultural activities (Busico et al., 2017). Shallow groundwater with agricultural and settlements land covering is more susceptible to contamination by anthropogenic activities. The high value ($Na^+ + K^+$) is influenced by the interaction between groundwater and rock (Maria et al., 2021).

Land Use Effect on Groundwater

Several groundwater samples were taken in paddy fields, settlements, and dry agricultural land. A total of five samples of groundwater were taken from wells located in paddy fields (SG3, SG1, SB9, SG57, and SB25), two samples were taken from wells located in dryland farming areas (SB3 and SB4), and ten samples were taken from wells located in settlement areas (SB60, SB2, SG2, SB1, SB52, SB50, SG4, SG15, SB16, and SB45) (Figure 8). The influence of land use on groundwater can be seen from the chemical composition of groundwater (Sánchez et al., 2017). The $CaHCO_3$ groundwater facies are the most abundant in the Baleendah – Soreang area.

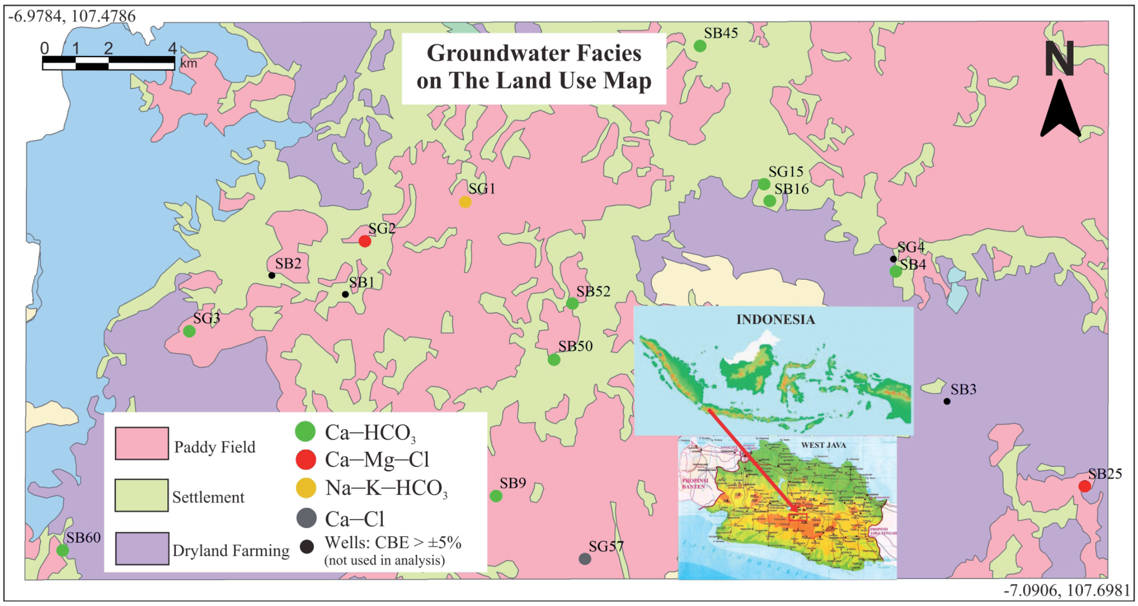

Figure 8. Variations in Groundwater Facies on The Land Use Map

Nine samples were in settlement areas, two in paddy fields, and one in dryland farming areas. The CaMgCl facies are in settlement (SG2) and paddy field areas (SB25). The $NaKHCO_3$ facies is in the paddy field area (SG1), and the CaCl facies is in the paddy field area (SG57). The effect of agricultural activities on groundwater in the Baleendah – Soreang area is indicated by the presence of $NaKHCO_3$ facies in the paddy fields (Figure 8). Enrichment of potassium (K^+) in groundwater can be caused by fertilizers (Notodarmojo, 2005). Anthropogenic influence is indicated by the presence of CaCl facies (Maria et al., 2021). The interaction between groundwater and volcanic rocks is characterized by Ca^+ enrichment in the groundwater facies. Ca^+ enrichment also indicates the influence of rock weathering. Meanwhile, the bicarbonate anion (HCO_3^-) is affected by the time it takes to store water in the rock and the environmental conditions of the surrounding air (atmosphere). Groundwater containing bicarbonate is suitable for bathing, washing, toileting, and irrigation. However, drinking requires special treatment, such as boiling or filtering it first (Rizqullah et al., 2015).

CONCLUSION

Based on its physical characteristic, the groundwater of this area belongs to the fresh groundwater type. Chemically, groundwater is dominantly influenced by the interaction of water with rocks, as indicated by the many $CaHCO_3$ facies, which are influenced by the dissolution process during the rainy season.

The influence of agricultural and anthropogenic activities on the interaction process between water and rock causes ion exchange which causes changes in groundwater, indicated by the presence of CaMgCl, $NaKHCO_3$, and CaCl facies.

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