DINAMIKA REKAYASA
http://dinarek.unsoed.ac.id

Volume 22 Nomor 1 (2026) Hal. 41-54
e-ISSN 2527-6131
http://jurnaldinarek.id

ANALISIS CEKUNGAN AIR TANAH BERBASIS KONTROL GEOLOGI: KAJIAN KARAKTERISTIK MAJOR KIMIA DAN POLA ALIRAN AIR TANAH DI LERENG TIMUR GUNUNG GEDE, KABUPATEN CIANJUR, PROVINSI JAWA BARAT

A ANALYSIS OF A GEOLOGICALLY CONTROLLED GROUNDWATER BASIN: MAJOR ION CHEMISTRY AND GROUNDWATER FLOW PATTERNS ON THE EASTERN SLOPE OF MOUNT GEDE, CIANJUR, WEST JAVA

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Abstrak

Pertumbuhan penduduk berbanding lurus dengan meningkatnya kebutuhan air, perubahan tata guna lahan menjadi kawasan permukiman turut mempengaruhi kapasitas cadangan air. Kajian di Kabupaten Cianjur, kebutuhan air penduduk dipenuhi dari air tanah, sebagian besar wilayahnya telah mengalami alih fungsi menjadi permukiman. Kondisi ini menegaskan pentingnya kajian sistem aliran air tanah untuk menjaga keberlanjutan sumber daya air. Secara geologi batuan tersusun atas batuan vulkanik tua dan hasil gunung api muda. Dengan nilai permeabilitas berkisar antara $5,789\times10^{-3}$ hingga $1,8752\times10^{-7}$ cm/det. Berdasarkan sifat fisik, air tanah menunjukkan perbedaan karakter dalam satu cekungan air tanah, nilai EC dan TDS cenderung meningkat ke arah hilir, mengindikasikan adanya interaksi air tanah. Kimia, air tanah memiliki fasies dengan kandungan mineral Mg-Ca, HCO3. Hal tersebut menunjukan aliran air tanah berada di fase transisi. Rasio Mg/Ca yang agak tinggi yang menunjukkan bahwa penguapan merupakan proses penting yang mengendalikan kimia air tanah, Ca-Mg atau Ca/Mg, fase ini terbentuk karena adanya pelarutan dari evaporasi dan adanya interaksi air dengan batuan yang tua relatif lebih lama. Fenomena yang terjadi memberikan Gambaran penting mengenai dinamika sistem aliran air tanah di Cianjur. Perkembangan aliran air tanah ini menjadi sangat penting untuk perencanaan dan pengelolaan sumber daya air di Kabupaten Cianjur.

Kata kunci: Cekungan Air Tanah, Hidrogeokimia, Kontrol Geologi, Pola Aliran Air Tanah

Abstract

Population growth is directly proportional to the increasing demand for water, while land-use changes into residential areas also affect the region's water storage capacity. In Cianjur Regency, residents' water needs are supplied by the Cianjur and Cibanteng sub-watersheds (Sub-DAS), most of which have undergone land conversion into settlements. This condition highlights the importance of studying groundwater flow systems to ensure the sustainability of water resources. Geologically, the area consists of old volcanic rocks and younger volcanic deposits, with permeability values ranging from 5.789×10^{-3} to 1.8752×10^{-7} cm/sec. Based on physical properties, groundwater shows different characteristics within a groundwater basin, EC and TDS values tend to increase downstream, indicating groundwater interaction. Chemically, the groundwater exhibits facies containing Mg-Ca, HCO_3 minerals, suggesting that the groundwater is in a transitional flow phase. The relatively high Mg/Ca ratio indicates that evaporation plays a significant role in controlling groundwater chemistry. The Ca-Mg or Ca/Mg phase forms due to dissolution processes from evaporation and prolonged interaction between water and older rocks. This phenomenon provides important insights into the dynamics of the groundwater flow system in Cianjur. The development of this groundwater flow is crucial for water resource planning and management in Cianjur Regency.

Keywords: Groundwater Basin, Hydrogeochemistry, Geological Control, Groundwater Flow Pattern

I. INTRODUCTION

Cianjur Regency is an area with a relatively dense population. According to data from the Central Statistics Agency [1], the population in Cianjur Regency has been increasing by around 2% annually. This condition has a direct impact on the rising demand for groundwater, as a larger population results in a greater need for water. The Groundwater Basin Map of West Java Province and the Special Capital Region of Jakarta [2] indicates that this study area falls within the Cianjur Groundwater Basin, with some parts classified as non-Basin areas.

The research focuses on two river streams, namely the Cibanteng Sub-Watershed and the Cianjur Sub-Watershed in Cianjur Regency. The northern boundary of the watershed area is the Cianjur Sub-Watershed, covering approximately 41.0 km², while the southern boundary is the Cibanteng Sub-Watershed, which spans about 28.8 km² because the rainwater that falls in these two watersheds will infiltrate into the Cianjur groundwater basin. The research location is situated in the eastern part of Mount Gede.

Regionally, the geological composition of the study area consists of ancient volcanic rocks and recent volcanic products. Based on the distribution of rocks in the area, groundwater availability is not uniform across the region; one of the factors influencing this variation is the geological conditions [3]. The geological characteristics of Mount Gede's volcanic deposits include layers of lava and other volcanic materials, which vary in type. The presence of springs, such as the Cirumput Spring, serves as evidence of volcanic activity. This spring is one of the water sources for PDAM Cianjur. The primary objective of this study is to determine the trends in the physical and chemical characteristics of groundwater in relation to geological conditions, as well as to understand how the physical and chemical properties of groundwater change with groundwater flow. Broadly, the study area encompasses three districts: Cugenang, Cianjur, and Pacet, all located within Cianjur Regency. This area is situated in the eastern part of Mount Gede.

II. LITERATUR REVIEW

A. Regional Geology

Based on the Cianjur Geological Map Sheet [4], the research area is composed of Quaternary volcanic rocks in the form of breccia, lahar, tuff, and lava flows from Mount Gede, with the youngest rocks in the form of basalt boulders that form small hills in the Cianjur plain. Tectonically, western Java in the Tertiary Period was a back-arc basin and a magmatic arc that migrated southward until the Quaternary [5]. The Bayah area is the meeting point between the Java Geoanticline and the Barisan Hills, forming a complex geological structure. Pulunggono and Martodjojo (1994) [6] identified three main structural lineament patterns in Java, namely the Meratus Pattern (NE–SW, oldest), the Sunda Pattern (N–S, younger), and the Java Pattern (E–W, youngest and still active today).

B. Hydrogeology of the Study Area

The research area is included in the Indonesian Hydrogeological Map Sheet IV: Sukabumi [7], published by the Directorate of Environmental Geology. This area is divided into a zone of scarce groundwater at the summit of Mount Gede and a zone with moderate to high groundwater productivity in the central part. The aquifers with medium to high productivity are composed of young volcanic deposits, including tuffaceous sandstone, lahar breccia, tuff, tuffaceous agglomerate, and vesicular lava, with a thickness reaching approximately 150 meters. Addition, the hydrogeological map indicates the presence of several large springs, which are manifestations of groundwater emerging at the surface.

In determining the groundwater basin in the study area, the approach used is based on permeability data. This data is employed to understand the parameters of the porous media constituting the aquifer, such as rock permeability. Permeability analysis utilizes field data with a classification approach [8].

Tabel 1. Permeability value reference [8].

No Sample	Permeability (cm/det)	Porosity (%)	Compressibility pascal -1 atau m2/N
ST 8 GB (andesite lava)	7,08E-10	15,64	3,98E-06
ST 1 DV (andesite lava)	6,42E-10	16,82	8,89E-08
ST 2 DV (andesite lava)	1,53E-10	18,09	8,13E-07
ST 10 GB (Grain Breccia)	1,30E-07	22,83	3,14E-07
ST 5 GB (Grain Breccia)	1,57E-07	26,88	3,36E-07
ST 3 DV (Grain Breccia)	2,00E-07	29,71	3,75E-07
ST 2 GP (Grain Breccia)	2,93E-07	26,99	2,14E-07
ST 7 GP (Grain Breccia)	1,43E-06	30,14	4,47E-07
ST 2 CP (Matrix Breccia)	1,00E-06	29,14	4,27E-07
ST 14 GB (Matrix Breccia	1,22E-06	31,05	4,17E-07
ST 3 PR (Matrix Breccia)	1,43E-06	28,91	4,22E-07
ST 8 IG (Lapili)	1,04E-05	36,31	7,84E-07
ST 6 IG (Lapili)	4,03E-05	35,91	7,37E-07
ST 15 IG (Lapili)	1,40E-05	30,55	7,79E-07
ST 7 GB (Coarse Tuff)	1,51E-04	39,21	9,67E-07
ST 14 NG (Coarse Tuff)	1,51E-03	39,54	9,41E-07
ST 3 NG (Coarse Tuff)	2,34E-03	36,24	8,54E-07
ST 16 NG (Coarse Tuff)	5,12E-04	40,22	7,29E-07
ST 10 NG (Smooth Tuff)	3,11E-04	39,67	3,72E-06
ST 3 NG (Smooth Tuff)	1,14E-04	45,14	2,78E-06
ST 5 NG (Smooth Tuff)	4,59E-04	45,14	2,09E-06
ST 4 NG (Smooth Tuff)	2,79E-05	41,62	2,44E-06

C. Groundwater Flow System

The interaction between groundwater and the natural environment is influenced by various chemical, physical, and kinetic components [9]. The conditions of these three aspects determine the characteristics of groundwater in a region. In areas with high chemical and thermal energy, mineral dissolution and oxidation occur, while in areas with low energy, water tends to accumulate and emerge at the surface as discharge flows. Environmental processes alone are not sufficient to make groundwater a significant geological agent; regional or basin-scale flow is needed to maintain the natural imbalance that triggers various geological phenomena. Toth (1999) explains that the groundwater flow system consists of recharge, transfer, and discharge zones, each with different mechanical energy characteristics. Additionally, during its journey from upstream to downstream, the chemical composition of groundwater undergoes evolution, with changes in the dominance of major ions such as HCO_3^- shifting to SO_4^{2-} and Cl^- [10], reflecting the dynamic interactions between water and rocks along the flow.

D. Groundwater Quality

Based on the Indonesian Ministry of Health Regulation No. 2/2023 concerning Drinking Water Quality Requirements [11], drinking water is considered safe for health if it meets the physical, microbiological, chemical, and radioactive parameters specified in the mandatory and additional parameters. The physical properties of water can be influenced by various factors:

a. Color

The color of water can originate from suspended particles or organic matter.

b. Taste and Odor

Odor is caused by organic compounds or microorganisms.

c. Electrical Conductivity (EC)

EC reflects the water's ability to conduct electricity, which is directly proportional to the TDS content.

d. Total Dissolved Solids (TDS)

TDS indicates the level of dissolved minerals, affected by rocks and human activities.

e. pH

The pH value reflects the acidity or alkalinity of the water, with the drinking water standard ranging between 6.5 and 8.5.

f. Temperature

Groundwater temperature indicates hyperthermal, mesothermal, and hypothermal zones and can be influenced by depth or subsurface magmatic activity, which also alters the physical and chemical properties of groundwater.

III. RESEARCH METHODS

The methods used in this research consist of geological mapping, determining groundwater basin boundaries, and measurements of physical and chemical properties of groundwater. To understand the geological conditions of the research area, the approach used is geological mapping through traversing or outcrop observation activities in the field [12]. Topography conditions are analyzed using a digital elevation model (DEM), while lithological distribution data are obtained from observations of outcrops found at the research location. The delineation of groundwater basins follows the method of Neuman (2007), where the boundary approach depends heavily on rock permeability, porosity, and hydraulic conductivity [13].

Groundwater observations and sampling were conducted during the dry season to ensure that water quality parameters such as pH, chemical content, and contaminants could be accurately detected without the influence of rainfall. In the Cianjur Sub-Watershed (Sub-DAS), 14 dug wells and 13 springs were sampled, while in the Cibanteng Sub-DAS, 1 borehole, 9 dug wells, and 13 springs were sampled. These observations focused on groundwater level elevation (MAT) and physical parameters such as electrical conductivity (EC), total dissolved solids

(TDS), and pH. In the chemical analysis of groundwater, groundwater samples were taken Standard Methods for the Examination of Water and Wastewater, 23rd Edition, 2017 (APHA), and the Indonesian National Standard of 2004 (SNI) to determine the anion and cation content in the water samples. Chemical analysis of groundwater samples was performed to determine the composition of anions and cations, using a Piper trilinear diagram to identify groundwater facies [14].

Subsequently, data processing and analysis were carried out. Geological data were used to identify lithological distribution and spring formation, as well as to delineate groundwater basin boundaries based on geological data and rock permeability, porosity, and hydraulic conductivity in the study area [8]. Dug wells are measured to determine groundwater table elevation, and contour maps of free groundwater surface, TDS, EC, and pH were created to interpret groundwater facies and quality. Based on these parameters, groundwater chemical analysis is then carried out to determine groundwater facies.

The research began with problem identification and the determination of the research focus. The primary objective was established as understanding the relationship between geological controls, major chemical characteristics, and groundwater flow patterns to analyze the groundwater basin system in the study area. The stages involved a preliminary study, which focused on collecting secondary data and reviewing literature. Based on this review, the research area boundaries, study location, and initial hypotheses were determined. Following the preliminary study, the researchers developed a field survey plan and sampling design. Next, geological mapping was conducted to identify lithological units and geological structures such as faults and fractures, along with DEM analysis and hydrogeological mapping. A geophysical survey was conducted to interpret aquifer depths and collect rock permeability data. The depth data that was successfully obtained was 200 m below the ground surface, the depth that was successfully interpreted was 200 m from the surface. The next step involved sampling groundwater from springs and wells, measuring parameters such as electrical conductivity (EC), total dissolved solids (TDS), pH, and temperature. Water flow patterns were then analyzed, and samples were sent to a laboratory for chemical analysis of major anions and cations, including Ca, Mg, Na, K, HCO_3, Cl, and SO_4. This stage aimed to interpret the chemical characteristics of the groundwater. Data were analyzed using Piper, Stiff, and Gibbs diagrams to identify groundwater facies and controlling factors. The final outcome was the integration of geological, geophysical, and basin data to provide a comprehensive understanding of the groundwater system in the study area.

IV. RESULTS AND DISCUSSION

Based on the geological mapping of the study area, the study area yielded 52 observation points. Based on field data analysis, the study area is divided into five rock units consisting of old and young volcanic products. The rocks included in the old volcanic products are supported-grain monomictic breccia and tuff, while the young volcanic units are supported-matrix monomictic breccia, supported-matrix polymictic breccia, and volcanic lava.

Breccia lithology is the result of old volcanic deposits composed of monomictic grain-supported breccia, generally characterized by a fresh orange-cream color, black weathering color, a fine-tuff matrix to very fine-tuff, andesite components, with gravel-cobble size, poorly sorted, open-packed, and soft. The matrix is fine to very fine tuff, with components of andesite, and sizes ranging from gravel to pebble. The sorting is poor, the packing is open, and the material is soft. The matrix of the fine to very fine tuff is typically creamy to orangish when fresh, turning to dark brown upon weathering, with angular grains, moderate sorting, and open packing. The andesite components are light gray when fresh and gray when weathered.

The tuff has a fresh color ranging from reddish cream to gray, while the weathered surface appears gray to brownish cream. The grain size of the tuff varies from coarse to fine, with angular grains that are moderately hard to easily crushable. The sorting is moderate to poor, and some fragments are fractured.

This breccia is the result of young volcanic deposits, the characteristics of supported matrix monomic breccia, generally have a fresh color of brownish-light brown ash, weathered color of grayish-reddish brown black, gravel-boulder grain size, angular grain shape, hard-rather hard, poor sorting, fine-coarse tuff matrix, andesite component. Andesite component with a fresh color of gray and brown weathered color, hypocrystalline granularity, porphyritic granularity, inequigranular packing, hypidiomorphic mineral form, subhedral crystal form, massive structure. Tuff matrix, fresh color cream-gray, weathered color black-reddish brown, tuff grain size fine to coarse, sub-angular, open packing, medium to poor sorting, massive.

Supported matrix polymict breccia generally has a fresh reddish-brown-orange color, a weathered light grayish-reddish brown, gravel-cobble grain size, a moderately angular grain shape, open packing, coarsening upward structure, moderately hard hardness, poor sorting. The rock components consist of andesite, medium-fine tuff and sandstone, the matrix is fine tuff - lapilli. Andesite component: has a fresh gray to blackish gray color, a weathered gray-orange color and aphanitic granularity. The tuff component has a fresh orange color, a fine-medium tuff grain size, a moderately angular grain shape. The sandstone component has a fresh gray color, a weathered gray-brownish color, a medium-coarse sand grain size, a moderately angular-rounded grain shape, moderate sorting, open grain relationships, a massive structure and soft hardness. The tuff matrix to lapilli has a fresh color of reddish-orange brown, the weathered color is brown to grayish brown and the tuff grain size is fine to lapilli, the grain shape is slightly angular.

Andesite lava, has a fresh gray color, a brownish gray weathered color, a mesocratic color index, aphanitic porphyry granularity, massive structure, and the observed mineral composition is quartz, plagioclase, a little k-feldspar, biotite and amphibole.

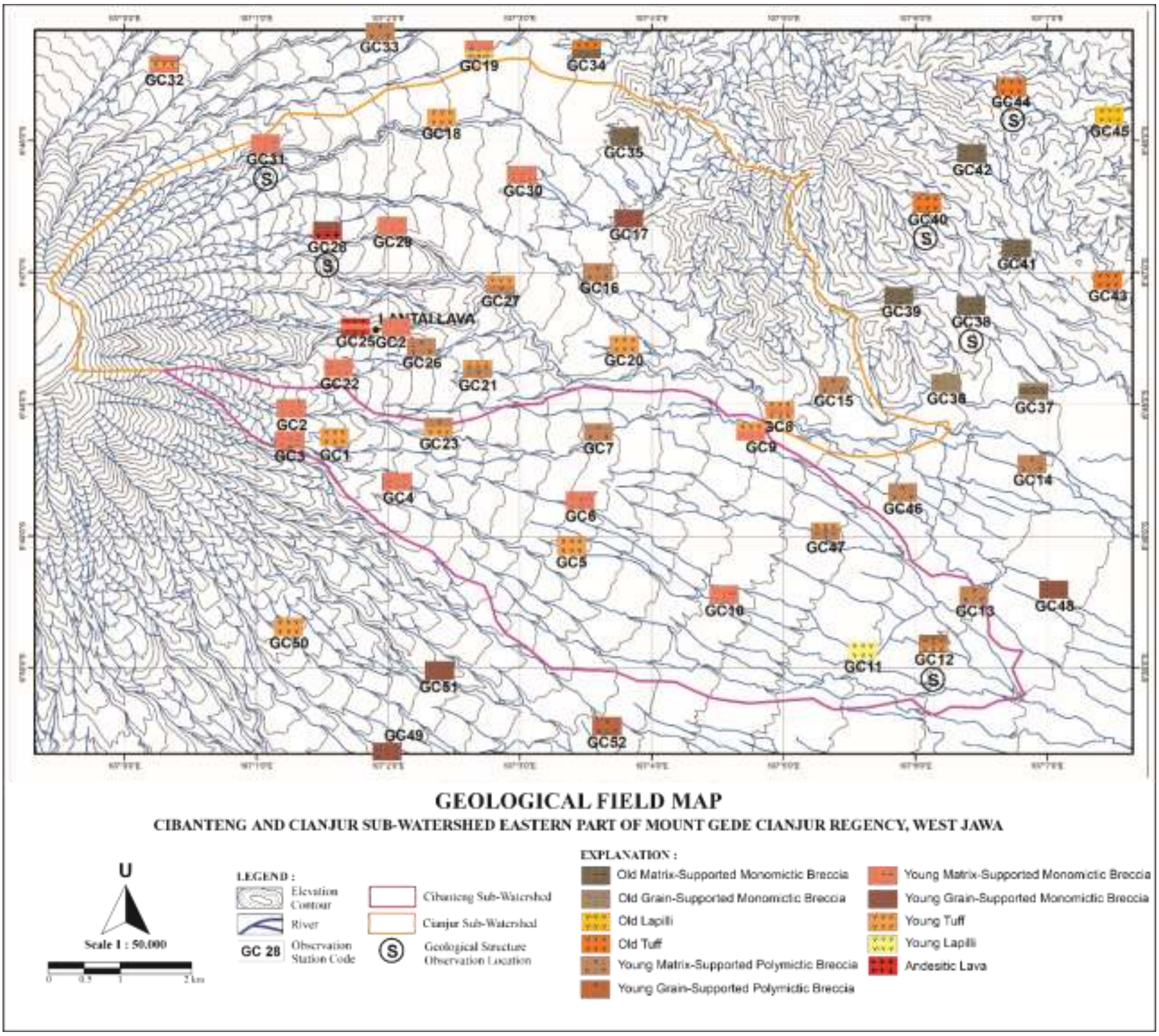

Figure 1. Geological field map

The results of the FFD analysis in the study area can be seen in Figure 2, which shows variations in density levels ranging from low, medium, to high. Low-density values dominate almost 60% of the study area and are spread along the outer and northern boundaries of the study area. Meanwhile, in the central, southern, and several points in the northeast and northwest of the study area, there are areas with high density values surrounded by medium density values.

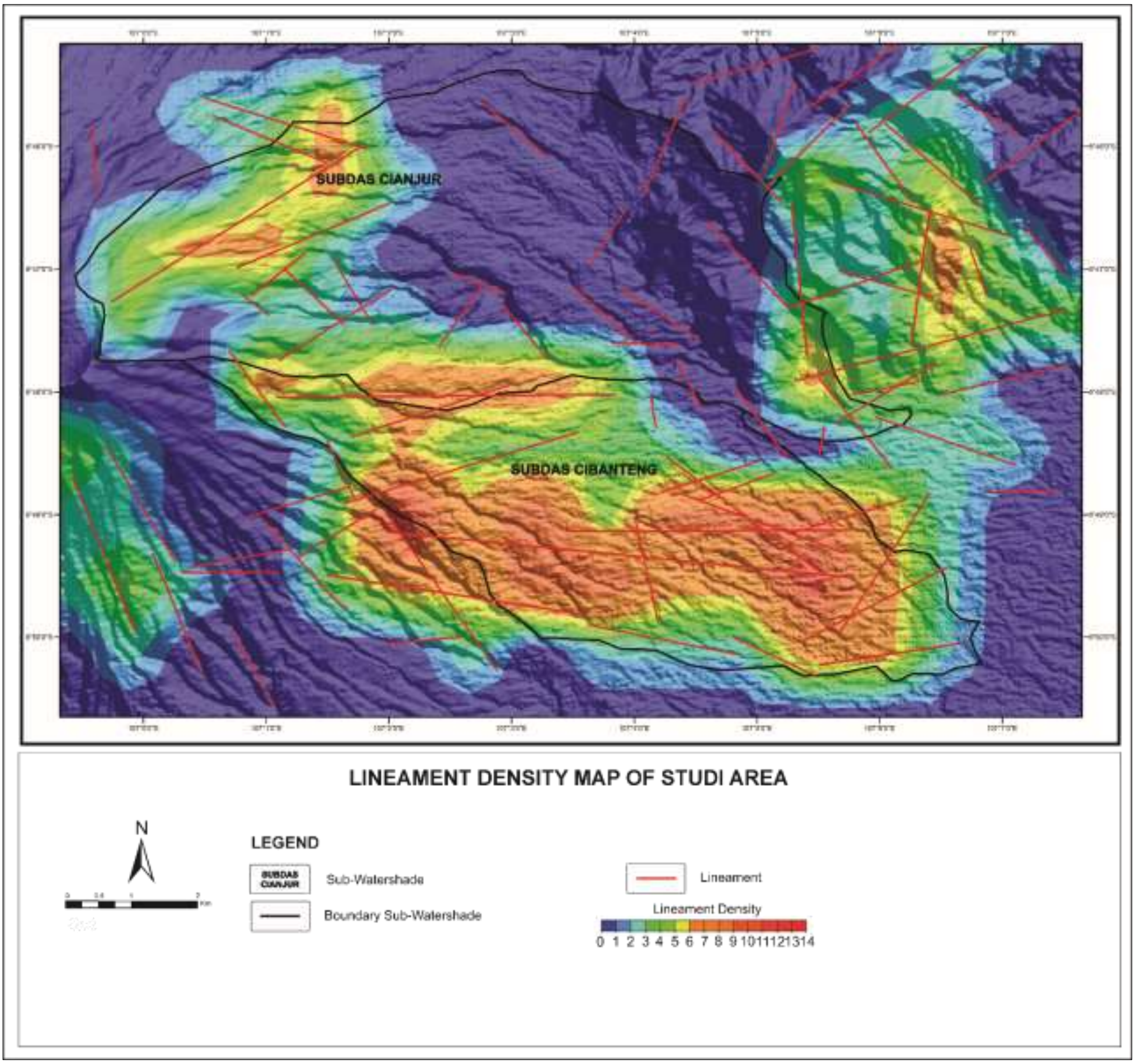

Figure 2. Lineament Density

A. Basin And Groundwater Flow Patterns

Based on the combined results of groundwater basin determination using geological approaches, geoelectrical cross-sections, and permeability. The depth data obtained reached 200 meters below the ground surface. The resistivity values from 100 sounding points across the investigation area were able to represent the entire region effectively, with the interpreted depth also reaching 200 meters from the surface. A total of 1,742 resistivity (ρ) values were collected, ranging from a minimum of 1 Ohm·m to a maximum of 6,554 Ohm·m [8].

The proximal zone shows andesite lava rocks. In addition, there are grain breccia rocks and matrix supported and a little lapillus. In the geoelectrical cross-section, andesite rocks continue downward vertically to a depth of about 200 meters. Above it, there is a layer between breccia and lapilli, with grain supported breccia at the base. In the medial facies, a transition zone between breccia and lapilli is seen associated with coarse tuff; at a depth of about 20 meters appears andesite lava blocks that continue for more than 200 meters. Meanwhile, the distal facies show a dominance of coarse tuff and lapilli, with fine tuff only appearing on the surface. At a depth of 50–100 meters, matrix supported breccia blocks were found, but no andesite lava rocks or grain supported breccia were found in this section based on the classification [8].

The results of the rock permeability of the research area can be seen in Table 2. The highest permeability value in the research area is around 5.789x10-3 found in the coarse tuff lithology, while the lowest permeability value with a value of 1.8752x10-7 cm/sec is found in the supported grain matrix breccia rock sample.

Tabel 2. Rock permeability value

Rock Type	Permeability (cm/sec)
Matrix Breccia	3,14744E-06
Lapili	1,60457E-05
Coarse Tuff	0,000578931
Smooth Tuff	9,05792E-05
Grain Breccia	1,87523E-07
Andesit Lava	7,02014E-10

Referring to the permeability classification, poorly permeable grain-supported breccia does not meet the criteria to function as an aquifer. The coarser tuff rocks exhibit the highest and most adequate permeability, followed by lapilli and fine tuff. Based on this permeability classification, the study area consists of two types of basin features: basin and non-basin/barrier areas (Figure 3).

Based on the results of field measurements from dugwell and spring of physical and chemical properties of groundwater, the electrical conductivity (EC) values range from 80 µS/cm to 310 µS/cm in the Cibanteng Sub-Watershed and from 60 µS/cm to 490 µS/cm in the Cianjur Sub-Watershed. The total dissolved solids (TDS) values range from 30 mg/l to 140 mg/l in the Cibanteng Sub-Watershed and from 20 mg/l to 240 mg/l.

Chemical analysis of groundwater in the field shows pH values ranging from 5.9 to 7.3 in the Cibanteng Sub-Watershed and from 4.6 to 7.8 in the Cianjur Sub-Watershed. The pH distribution indicates that higher pH values are located in the southwestern part of the study area and partly in the southeastern area, which is downstream of the groundwater flow. Moving towards the northeast, the pH values tend to decrease.

Higher EC and TDS values in the Cianjur Sub-Watershed are generally found in its eastern part. Based on groundwater table positions, groundwater flow was reconstructed. The groundwater flow map also analyzes flow directions, water chemistry, and potential contamination pathways [17].

The groundwater gradient ranges from 1063,52 to 515,6 meters above sea level. These results suggest that groundwater flows relatively from the west toward the southeast, following the topography of the study area. To observe the distribution of sampling points, please refer to Figure 3.

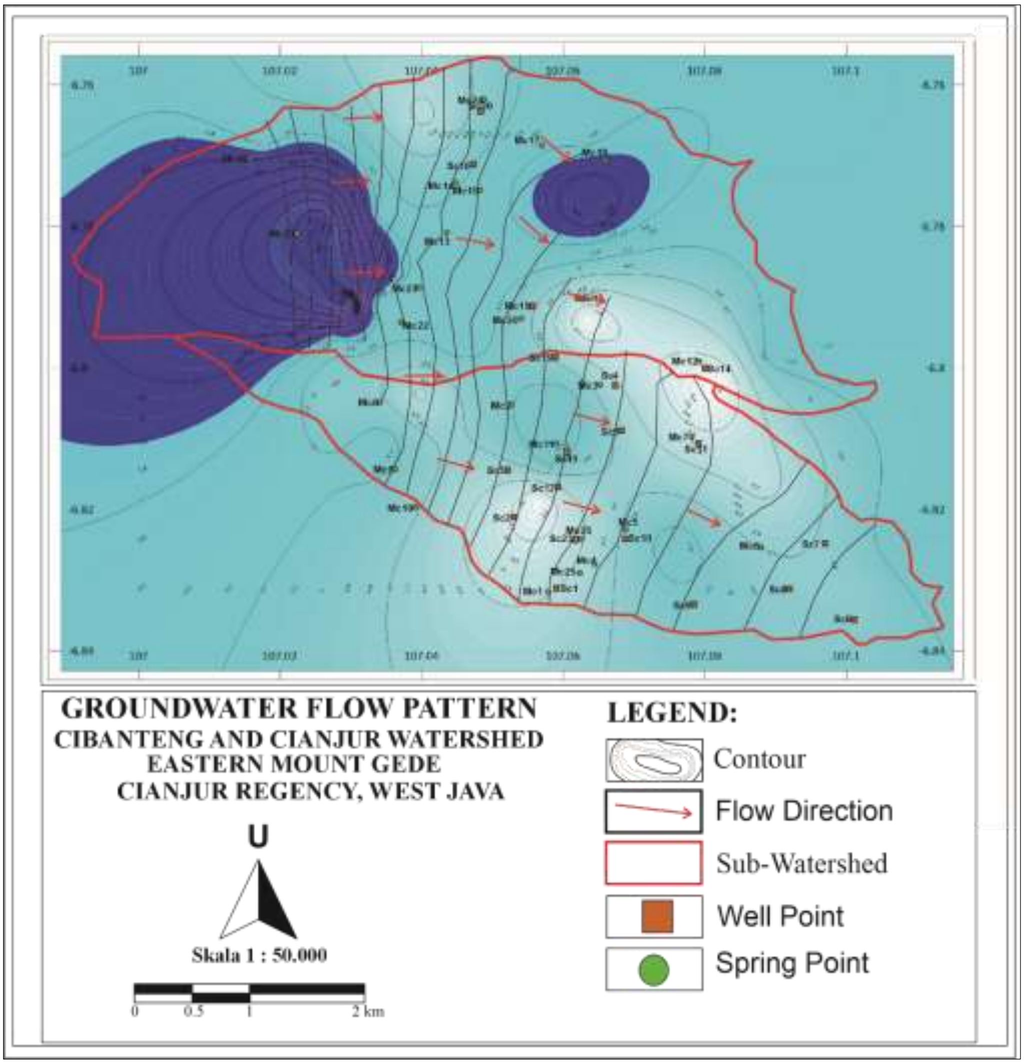

Figure 3. Groundwater Flow Patterns and Groundwater Basins

During the groundwater flow process, the flow path follows the type of rocks it passes through. Several flow patterns are observed in the study area, including relatively uniform flow patterns and those that show deviations or bends, which are caused by geological processes and differences in older lithologies. As groundwater flows downstream, both EC (electrical conductivity) and TDS (total dissolved solids) values tend to increase. This occurs due to mineral or soil erosion that is carried by the river, resulting from interactions between the groundwater and the surrounding rocks.

A. Groundwater Chemical Analysis

Based on the chemical properties of groundwater in the study area, several characteristics are influenced by basins formed by rocks with non-porous (impermeable) layers. Using a permeability analysis approach, the groundwater basins are grouped and marked with several lines on Figure 4. The lines representing a single group indicate interconnected basins with groundwater flow between them. However, as shown in Figure 4, station SC 17 exhibits a disconnected flow, which is caused by a barrier or obstruction. Lithological analysis of the rocks in that area indicates that the composition consists of tuff lithology from old volcanic deposits and and the lineament density analysis shows that this area has a medium density value Figure 4.

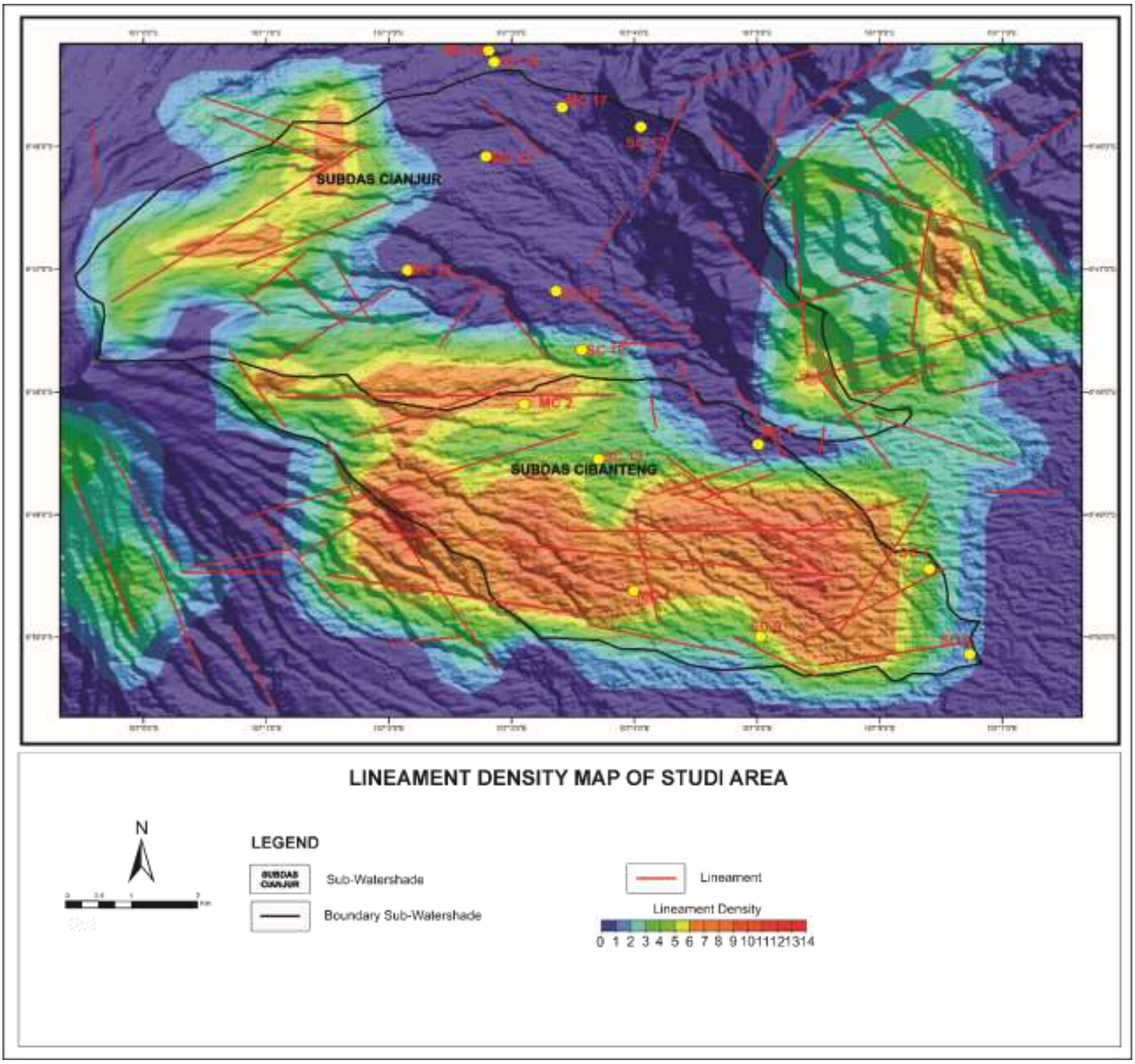

Figure 4. Lineament density and groundwater chemistry

In analyzing the main ions such as Na+, K+, Ca2+, Mg2+, Cl-, HCO3 and SO42 is the basis for understanding the hydrogeochemical characteristics of groundwater [18] [19]. Groundwater tests were conducted at the Water Laboratory, Environmental Engineering, Faculty of Civil & Environmental Engineering, Bandung Institute of Technology, then analyzed to determine the groundwater facies. The initial step for facies analysis is to convert the ion concentration data from laboratory analysis into milliequivalents per liter (mg/l). The results of the ion concentration unit conversion can be seen in the following table 3:

Table 3. Groundwater consentration result

No	Kode Sampel	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	HCO3 (mg/l)	SO4 (mg/l)
1	SC2	5,27	2,12	8,34	7,37	8,75	55,4	4
2	SC6	8,75	1,7	22,5	10,7	9,73	102	22,4
3	SC7	7,53	1,33	10	6,37	6,81	63,7	4
4	SC9	7,56	1,72	16,7	6,82	5,84	94,7	8,59
5	SC13	5,64	1,66	12,5	6,85	6,81	63,7	4
6	SC17	2,5	0,255	5	4,42	7,78	13,8	5,56
7	SC18	5,69	0,739	14,2	4,86	10,7	47,1	4
8	SC19	6,37	1,58	11,8	3,84	8,75	74,8	4
9	SC20	4,54	2,28	12,5	5,86	8,75	41,5	4
10	MC2	3,32	2,208	14,2	6,36	3,89	69,2	4
11	MC4	3,19	2,13	15,8	6,31	4,86	76,1	4
12	MC7	5,08	2,51	15,8	10,3	6,81	91,4	4
13	MC15	5,96	2,17	25	9,24	8,75	83,1	9,37
14	MC17	6,79	3,34	26,7	11,1	25,3	88,6	7,93
15	MC23	6,36	3,46	21,7	8,28	9,73	77,5	4
16	MC24	5,83	1,33	17,5	10,3	10,7	69,3	4

B. Piper Diagram

Hydrogeochemical characterization can be performed by identifying groundwater facies [19] [20]. This identification is conducted to analyze water data across various plot diagrams. The Piper diagram is a simple and widely used method to determine the type of groundwater characterized by the dominant ions. The data plotted on the Piper diagram (1944) include the percentage of Ca, Na+K, Mg ions in the cation triangle, and the percentage of Cl, SO4, HCO3; ions in the anion triangle.

The results of the plotting on the Piper diagram (Figure 5) show that in the cation triangle (bottom left), most samples fall into the category of no dominant cation type, while others are classified as Calcium (Ca) type. In the anion triangle (bottom right), most samples are classified as Bicarbonate (HCO3;) type, with only one sample indicating no dominant anion type. Based on the Piper diagram interpretation, each water sample is grouped into four groundwater facies categories, which are as follows:

- **Ca, HCO3; facies**: SC18, MC4, MC15, MC17, MC23
- **Mg-Ca, HCO3; facies**: SC7, MC7, SC17
- **Ca-Mg, HCO3; facies**: SC6, SC9, SC13, SCS19, SC20, MC2, MC24

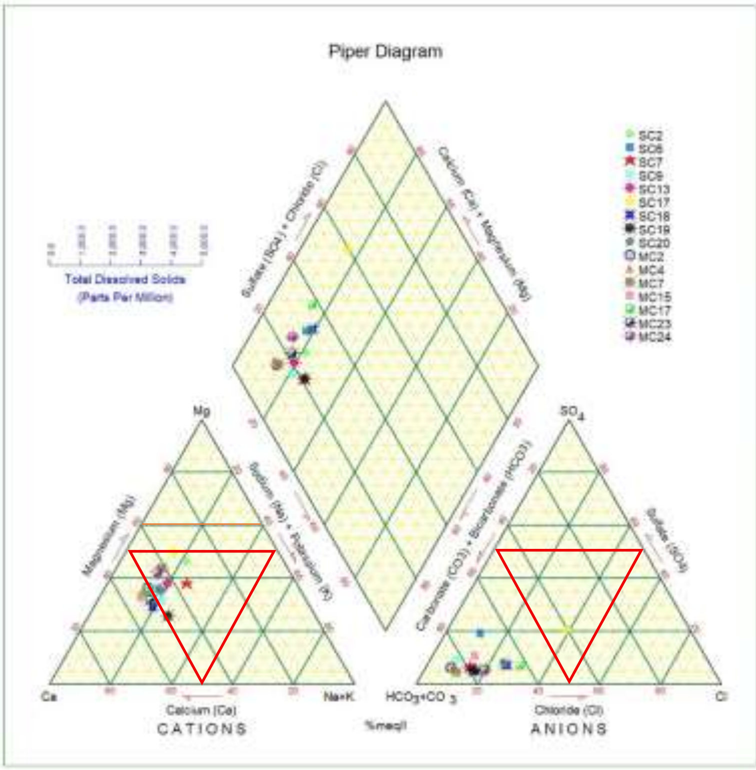

Figure 5. Piper Diagram of the Research Area

Based on the analysis results, the facies in the research area are dominated by Ca, HCO3- facies related to the water-rock interaction process, interaction with rainwater. However, there are facies that are different from the others, namely in the SC17 well sample which has Mg-Ca, HCO3 facies. This shows that the water flow that occurs is in a transition phase because it is dominated by Ca-Mg or Ca/Mg [21]. This phase is formed due to the dissolution of evaporation and the interaction of water with relatively older rocks and because of the structure.

b. Gibbs Diagram

The Gibbs diagram is a graphical representation used to determine the relationship between water composition and aquifer lithology [22]. This diagram classifies water into three distinct fields: precipitation dominance, evaporation dominance, and rock-water interaction dominance [23]. The results of plotting the groundwater samples on the Gibbs diagram are presented in Figure 6.

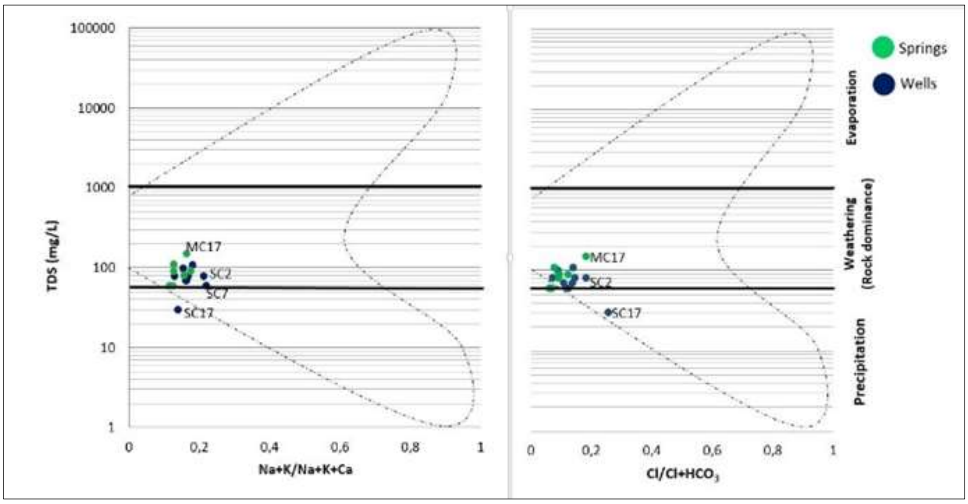

Figure 6. Gibbs Diagram of The Research Area

Based on the plotting results, the samples can be divided into two groups. The majority of the water samples fall into the group influenced by rock-water interaction. This group represents a mixed groundwater type, where the groundwater initially resides in the precipitation zone, which is characteristic of local groundwater, and then moves towards the weathering zone, where the interaction with rocks is relatively high. The other group is located within the precipitation zone, represented by the SC17 station.

In rock-water interaction, ions are the primary factors affecting the geochemistry of groundwater [15][16]. The ion concentrations in groundwater depend on the hydrogeochemical processes involved within the aquifer system. Geologically, older rocks, mainly consisting of tuff lithology, are found in the eastern part of the study area. The groundwater facies results indicate Mg-Ca, HCO3, suggesting that the groundwater is in a transitional phase. The relatively high Mg^{2+}/Ca^{2+} ratio indicates that evaporation is a significant geochemical process controlling the groundwater chemistry. The Ca-Mg or Ca/Mg-HCO3 phase forms due to evaporation dissolution processes and prolonged interactions between water and older rocks.

C. Discussion

The delineation of the groundwater basin is limited both vertically and horizontally. Vertically, the boundary is defined by boreholes or geophysical surveys indicating that the rocks are impermeable, supported by breccia grains supported. Horizontally, the boundary is determined through geological mapping, which shows the presence of coarse tuff rocks. Based on the direction of groundwater flow, variations are observed due to the presence of barriers that cause the flow to bend. Geologically, these barriers are formed by older rocks compared to the surrounding formations, which disrupt continuous flow and due to the presence of structure.

Another approach is seen from the trend graph of the physical and chemical characteristics of groundwater, it can be seen that the EC and TDS values of the elevation are higher downstream, this condition indicates the presence of groundwater interaction. Based on chemical analyses, the Ca-Mg or Ca/Mg HCO3, phases are formed due to dissolution processes driven by evaporation and prolonged interactions between water and older rocks and due to the presence of structure. Additionally, the Gibbs diagram plotting shows that the groundwater initially resided in the precipitation zone, representing local groundwater, before moving toward the weathering zone with higher rock interaction. A limitation of this study is the lack of data on the physical and chemical properties of groundwater collected during two different seasons, which could serve as comparative data for delineating the groundwater basin. Furthermore, no boreholes were drilled to verify the subsurface conditions.

V. CONCLUSION

A. Conclusion

Based on the mapping results, the study area is composed of five types of rocks resulting from volcanic activity of both old and young volcanoes. The older volcanic rocks include monomict grain-supported breccia and tuff, while the younger volcanic rocks consist of monomict matrix-supported breccia, polymict matrix-supported breccia, and volcanic lava. The permeability values of these rocks range from 5.8×10^{-3} to 1.9×10^{-7} cm/day. These impermeable or non-porous rocks serve as boundaries for the groundwater basin. The groundwater flow system within this basin develops in the research area, classified as a local flow system. Physical property analysis shows that the electrical conductivity (EC) values range from 60 µS/cm to 490 µS/cm, and total dissolved solids (TDS) range from 20 mg/l to 240 mg/l, increasing downstream. This trend indicates active interactions between groundwater and the surrounding rocks due to reactions between water, minerals, and soil. Observations also reveal two patterns of groundwater basins that influence flow dynamics.

Chemical analysis using the Piper diagram shows that the dominant groundwater facies are characterized by Ca and Mg cations, which are interpreted to originate from the dissolution of volcanic rocks. For anions, HCO_3^- is predominant, formed through interactions between groundwater and atmospheric CO_2 dissolved in the water.

B. Suggestion

Based on the observations and data processing in this study, several recommendations are made, including: (1) Follow-up research is needed regarding hydrogeological conditions and more detailed permeability testing to obtain more accurate data; (2) Continuous research is needed, not only during the dry season but also during the rainy season to obtain more accurate data, as conditions during the dry and rainy seasons can differ.

ACKNOWLEGMENT

The author would like to express his deepest gratitude to Dr. T. Yan W. M. Iskandarsyah and Prof. Hendarmawan for their guidance, direction, and scientific support throughout the research process. He also extends his gratitude to the Directorate General of Higher Education, Research, and Technology for their financial support through the 2020 DIKTI Grant, which has made this research possible.

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