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Water Quality and Hydrochemical Studies in Watersheds Cikapundung River Case Study

Peny Supriatno[1], Rizky Syaputra[2], Robertho Kadji[3], Lia Alfianita[4]
[1,2,3,4]*Mining Engineering, Faculty of Engineering and Design, Institut Teknologi Sains Bandung (ITSB), Cikarang*
penysupriatno@itsb.ac.id, rizkysy@students.itb.ac.id, 22120018@mahasiswa.itb.ac.id, 22120017@mahasiswa.itb.ac.id

Abstract

Cikapundung River is one of the rivers that plays an important role as a water source in the city of Bandung. This river has great potential to be used as water supply in the city of Bandung. For further utilization, it is necessary to study the quality and hydrochemistry of water in the watershed (DAS), especially in the Cikapundung River. Based on the studies that have been carried out, it was found that the water quality is quite poor. Poor water quality is caused by a continuous process of pollution, which causes changes in the value of the physical and chemical parameters of water in the Cikapundung watershed. This process is further supported by the occurrence of dilution caused by the high intensity of rain in the city of Bandung. According to the graphical representation of the hydrochemistry of water, the type of water in the form of calcium bicarbonate was obtained based on the Piper Diagram. Bicarbonate water comes from the weathering of rocks or minerals near the surface. Supported by graphical representation using Durov Diagram, water in the Cikapundung watershed is intermediate water that has undergone ion exchange. This is evidenced by the Stiff Diagram which groups alkaline earth cations which are larger than alkali metals, and weak acid anions which are larger than strong acid anions. These three graphic representatives provide information about the evolutionary processes that occur in the Cikapundung watershed.

Keywords
Cikapundung watershed; water quality; water hydrochemistry

I. Introduction

Cikapundung River is a river that flows from north to south of Bandung City which has important value for the surrounding community. Over time the area around the river has changed as a result of human activities, such as agricultural, plantation, residential and industrial activities. These activities can affect the quality of river bodies due to the generated wastes. According to Kurniadie et al (2016) the water quality of the Cikapundung River has decreased, especially in the downstream area. Changes in river quality are caused by domestic waste, plantation waste, and industrial waste.

The Cikapundung Watershed (DAS) is one part of the Citarum watershed, which is the largest and longest river in West Java Province. This watershed located in the Bandung Basin has a catchment area of 14,211 hectares. Cikapundung watershed has a function as the main drainage in the center of Bandung City, until now it is still potential as a provider of raw water for the needs of the population even though the monthly water discharge has decreased in the range of 20 to 30% from normal conditions (Maria, 2008).

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The rapid economic growth and development in the city of Bandung has caused the Cikapundung River to change its function. The expansion of the development area makes green land a residential area. The existence of industry with its pollution and potential pollutant, has an impact on the destruction of ecosystems and the environment. These things cause the river to be in quite a worrying condition. Water is also used as one way of attracting tourists to the nation (Woldemaryam, 2020). Water is the source of life for humans, as well as all living things in the world (Lubis, 2021). Water as a vital natural resource and controls the needs of all living things needs to be managed properly (Hanif, 2021). To be able to identify and see water quality along the Cikapundung watershed, water samples were taken which consisted of measuring the physical and chemical parameters of water at several points.

1.1 Overview

The Cikapundung River crosses the city of Bandung along 15.50 km of which 10.57 km (about 68.20% of the total length) is a densely populated residential area. The river's elevation ranges from 650 to 2067 masl, with an upstream slope of 3 to 10% and a downstream slope of 0 to 3%. This river originates from a spring located on Mount Bukit Tunggal, forms *an outlet* and unites to form a river (Sofyan, 2004).

The Cikapundung River is a river that divides the city of Bandung with a length of 28 km, and crosses 11 sub-districts in 3 districts (Bandung Regency and West Bandung Regency) and the city (Bandung City). This river stretches from the north of Bandung to the south. This river has its headwaters in the areas of Cigulung and Cikapundung, Maribaya, Lembang whose water comes from Curug Ciomas. The Cikapundung River empties into the Citarum River in Bale Endah (Bandung Regency) and is one of the main rivers that supply water to the Citarum River.

1.2 Geomorphology

Geomorphologically, the Cikapundung River is included in the Bandung Lake plain unit, this unit has a wide coverage extending from west to east. With a unit area of about 20% of the Bandung Basin. This plain is an ancient lake sediment that has dried up thousands of years ago. The main river is the Citarum River which divides the plains of Lake Bandung. So Citarum is the lowest point of the Bandung Basin.

1.3 Hydrogeology

Bandung is an area that is part of the Bandung Basin. This basin is predominantly covered by volcanic products and lake deposits. The average amount of rainfall is 2000 mm/year, during the dry season (June to September with rainfall less than 50 mm/month. The other 8 months are the rainy season with rainfall varying between 150 to 350 mm/month. The Cikapundung River is a part of the Cikapundung watershed that functions as the main drainage in the center of Bandung City. The youngest sediment is the Cikapundung River sedimentary river as a release material that ranges in age from Pliotocene to Holocene (current conditions). The area around the Cikapundung River area is included in the shallow groundwater system (< 35m).

Shallow groundwater system recharge comes from direct infiltration from rainwater and indirect infiltration from rivers, irrigation canals, and rice fields. The Cikapundung River flows from north to south, passing through 3 sedimentary formations Cibeureum, Cikapundung, and Kosambi. All of these formations are located at the bottom of rivers and riverbanks. Due to the increase in population, area and industrial growth, the quality of river water is divided into 2 conditions, namely the first good condition in the upstream part and the second bad condition in the downstream part.

II. Review of Literature

2.1 Water Quality

Water quality is the nature of water and the content of living things, substances, energy or other components in water. Water quality is a description of the suitability or suitability of water for certain uses, such as drinking water, fisheries, irrigation, industry, recreation and so on. Water quality can be determined by testing the parameters of the physical, chemical and biological properties of water. Physical parameters measure temperature, turbidity, dissolved solids, and so on. Chemical parameters measure metal content, DO and BOD as well as biological parameters (microorganisms).

2.2 Water Quality Standard Criteria

The water quality standard is a measure of the limit or level of living things, substances, energy or components that exist, and must be tolerated or are possible to limit their existence in water bodies. Rivers must meet river water quality standards which will become a place for liquid waste disposal, so that water damage or river water pollutants can be controlled or even avoided. According to Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management, it states that the water quality is set into 4 classes, namely:

1) First class, is water whose designation can be used for drinking water raw water, and/or other designations that require the same water quality as that use.
2) Second class, is water whose designation can be used for water recreation infrastructure/facilities, freshwater fish cultivation, animal husbandry, water for irrigating crops, and/or other designations that require the same water quality as that use.
3) Third class, is water whose designation can be used for freshwater fish cultivation, animal husbandry, water for irrigating plants, and/or other designations that require the same water quality as that use.
4) Fourth class, is water whose designation can be used to irrigate crops and/or other uses that require the same water quality as that use.

2.3 Hydrochemistry

Hydrochemistry or hydrochemical facies is a function to reflect fluid kinetics and water flow patterns in a system (Back, 1966; Fetter, 1994). Hydrochemical facies is the chemical character of a solution in a hydrological system, to reflect the chemical processes that occur between mineral chemistry and water flow patterns that are influenced by the genetics of a natural system.

a. Ionic Equilibrium

Ionic equilibrium is a calculation to test the equilibrium that occurs between anions and cations in a solution or compound . Ion equilibrium analysis uses charge balance error (CBE) calculations. Generally, the acceptable CBE value is less than 5% (Frazee, 1979). If the CBE is more than 5%, it is usually caused by errors that occur during the analysis, or even because the concentration of anions or cations is relatively too large.

$$CBE\,(\%) = \left(\frac{\sum Kation - \sum Anion}{\sum Kation + \sum Anion}\right) x100\% \qquad \text{(equation } \mathbf{1}\text{)}$$

Then the CBE calculation is carried out using equation 1 by first changing the unit from mg/l to mEq/l using equation 2 and equation 3.

$$mEq/l = \left(\frac{miligram\,ion}{berat\ ekuivalen}\right) \qquad \text{(equation } \mathbf{2}\text{)}$$

$$berat\ ekuivalen = \left(\frac{berat\ molekul}{valensi\ ion}\right) \qquad \text{(equation } \mathbf{3}\text{)}$$

b. Piper Chart

The main ionic species found in water are Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, HCO^{3-} and SO_4^{2-}. The piper diagram shows the percentages of the three ion groups. By grouping Na^{+} and K^{+}, the principal cations can be *plotted* on a piper diagram. Likewise for CO_3^{2-} and HCO^{3}, the main anions can be *plotted* on a piper diagram. This diagram serves to group the types or species of water samples (Figure 1).

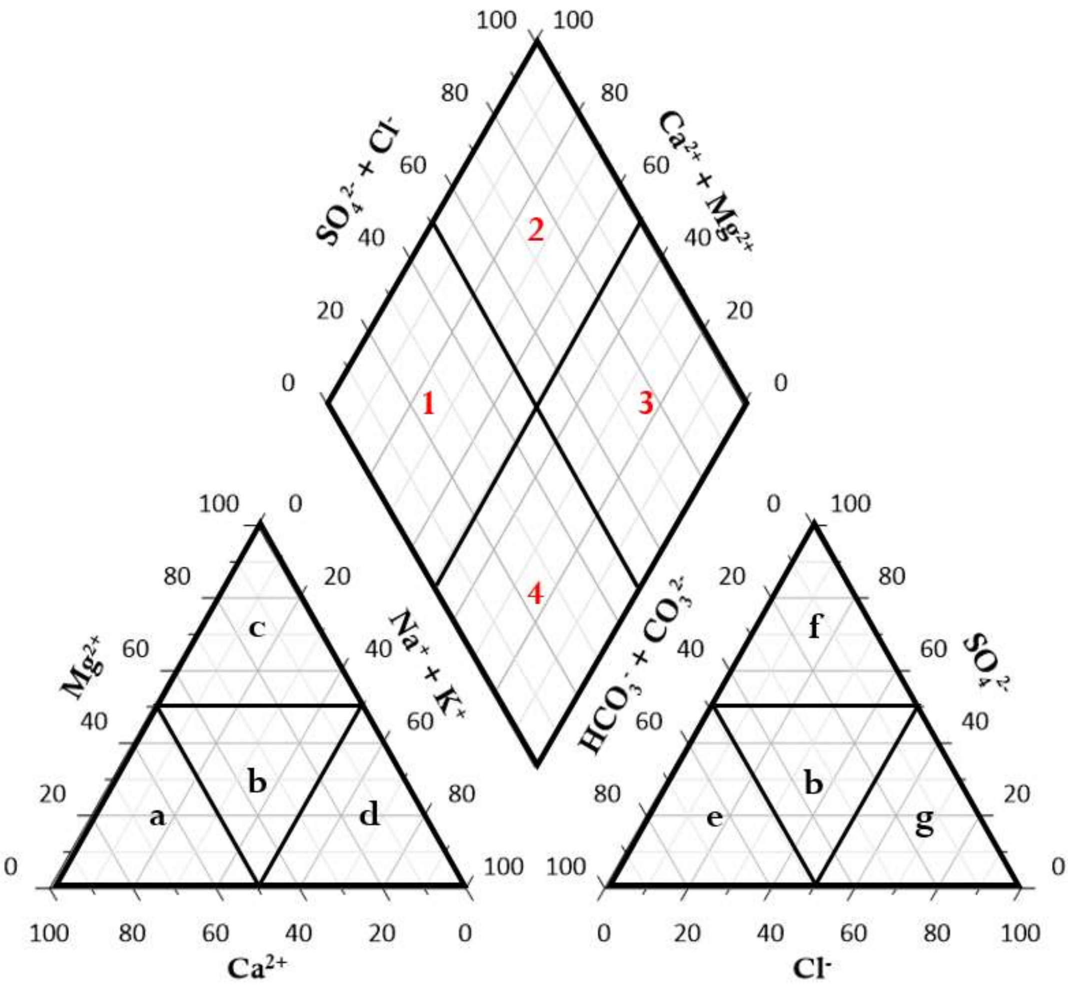

Figure 1. *Piper diagram (Redrawn from Fetter, 2000)*

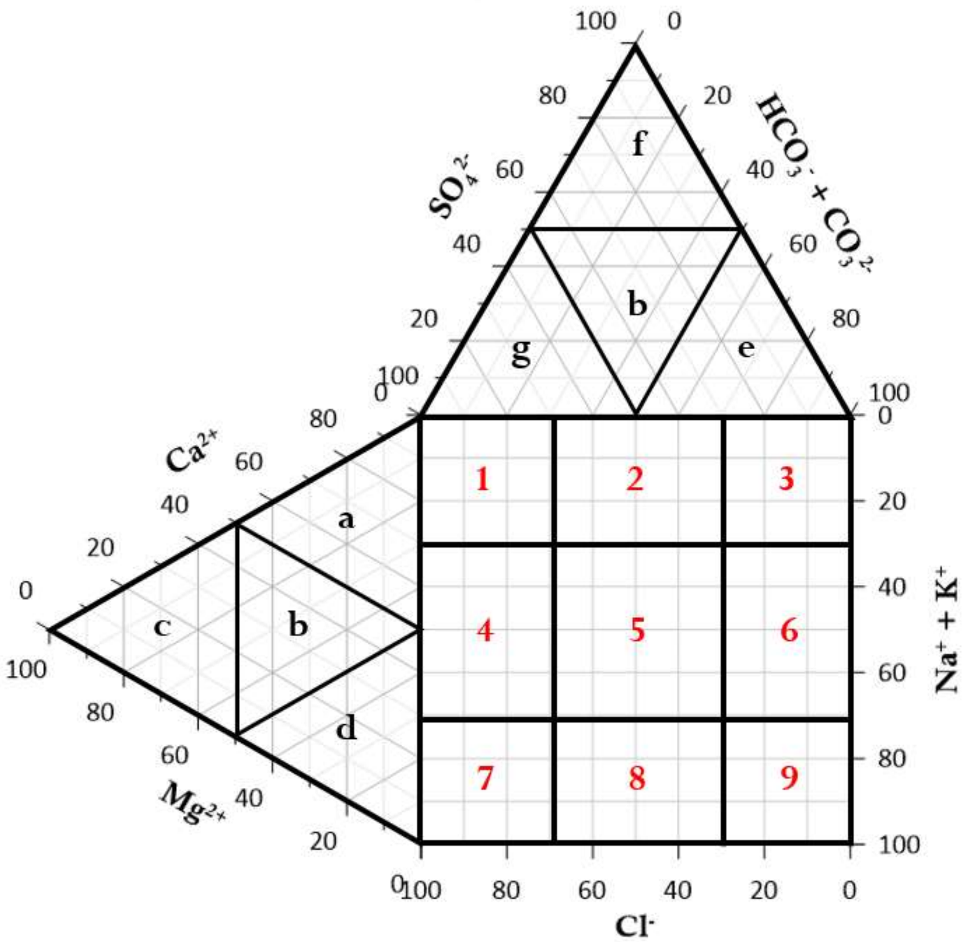

Figure 2. *Durov Diagram (Redrawn from Durov, 1948)*

c. Durov Chart

The Durov diagram is based on the milliequivalent percentage of the principal ion. The cation values are *plotted* on the left triangle and anions are plotted on the upper triangle, then the data points are projected onto the sides of the square at the base of each triangle. The data points projected along the base of the triangle are perpendicular to the third axis of each triangle. By changing the parameters of the two triangles, it is possible to detect different elements (Figure 2).

d. Stiff Diagram

The stiff diagram is used to make visual comparisons of ions from different water sources. The larger the polygonal area, the greater the concentration of various ions. A polygonal shape is made up of four parallel horizontal axes extending on either side of the vertical axis. Cations are *plotted* in milliequivalents/liter to the left of the zero axis, and anions are *plotted* in milliequivalents per liter to the right of the zero axis. The use of a stiff diagram in an area, where there is water containing minerals in certain parts of the *aquifer system.* The *isocon line* represents the total dissolved solids in the water at a given location.

III. Research Method

3.1 Sampling

Water samples were taken as many as 3 (three) samples at the Cikapundung River location, starting from the Cikapundung Terrace (CKD-01), Wastukencana (CKD-02) and Braga (CKD-03) sections which can be seen in Figure 3. Samples are stored in special bottles 500 ml without filtering or acidification. The water sample is considered a representative sample to be analyzed for differences in acidity (pH), as well as by reviewing the content of anions and cations in the water from 3 different collection points. Samples were taken based on the appearance of the area from densely populated areas to sparsely populated areas, to see how much influence the activities of residents around the river area had on the quality of the river water produced.

Figure 3. *Location of Water Sampling in the Cikapundung Watershed*

3.2 Water Quality Test

Water samples that have been taken from the Cikapundung watershed will then be tested physically and chemically for the quality of the water they contain. A 100 ml water sample was measured for the physical properties of the water, including the degree of acidity (pH), total dissolved solids (TDS), electrical conductivity (EC) and temperature using a *multiparameter* . Then the water sample was filtered using *a syringe filter with* a size of 0.22 m. Filtering is carried out so that the sample used is safe from particles that can interfere with the measurement process, in addition this process is carried out to obtain a good ionic balance from the sample, in accordance with actual conditions in nature or natural water conditions. After the filtration process, 50 ml of water was measured for the chemical properties of the water, including the content of anions and cations using an *inductively coupled plasma – mass spectrometer* (ICP-MS) and *ion chromatography* (IC). The content of physical and chemical properties of water from samples of the Cikapundung watershed is shown in Table 1.

Table 1. Cikapundung Watershed Water Quality

Parameter	Unit	CKD-01	CKD-02	CKD-03
pH		7.61	7.82	7.91
TDS	(mg/L)	84.32	95,70	92.12
DHL/EC	(µm hos/cm)	196	208	212
Temperature	(°C)	25.2	25.8	24.9
Li	(mg/L)	<0.01	<0.01	<0.01
Na	(mg/L)	7.53	8.43	9.35
Mg	(mg/L)	4.84	5.09	5.11
K	(mg/L)	3.86	4.44	4.54
Ca	(mg/L)	14.62	16.53	17.36
Fe	(mg/L)	0.56	0.49	0.66
Ni	(mg/L)	0.08	0.07	0.07
Cu	(mg/L)	0.22	0.24	0.27
Zn	(mg/L)	0.46	0.49	0.54
F	(mg/L)	1.13	1.15	1.18
NO_3	(mg/L)	11.99	13.00	13.29
NO_2	(mg/L)	1.68	2.72	2.76
Cl	(mg/L)	8.02	8.43	9.20
SO_4	(mg/L)	7.49	10.26	11.64
HCO_3	(mg/L)	58,47	56.13	55.84

IV. Results and Discussion

4.1 Analysis of Physical Properties of Water Quality in Cikapundung Watershed

a. Acidity

The degree of acidity (pH) is one of the most frequently used measurements, to determine the acidity of water, and whether or not it is feasible to use it for daily activities. According to the Appendix of River Water Quality Standards PP No. 22 of 2021, the applicable acidity (pH) is between 6 to 9. Based on the measurements made, it was found that the degree of acidity is still classified as safe to use because it has a value range between 7.91 to 7.61, with relatively alkaline conditions. The degree of acidity is closely related to carbon dioxide and alkalinity, the higher the pH value, the higher the alkalinity and the lower the free carbon dioxide value. The lower the pH value, the more corrosive it is and will affect the toxicity of a chemical compound. The degree of acidity has increased in value from upstream to downstream conditions, also caused by indications of the addition of alkaline elements that make Cikapundung River water have an increased pH, usually from domestic waste or community waste, such as water used for bathing, washing, or household waste which is getting bigger downstream.

b. Electrical Conductivity

Electrical conductivity (EC) is the ability of a fluid or water to conduct electricity or induce electricity from ion molecules. Based on the tests carried out, the electrical conductivity varies between 196 to 212 m. This value tends to increase along with the higher value of TDS dissolved in the water. Based on field measurements, it was found that the electrical conductivity or salinity of the water is safe to be used as drinking water, but it is not recommended for direct consumption. For health and hygiene factors, further *treatment* is needed so that the water can be used. Another factor is the influence of dissolved suspension and organic pollution.

c. Total Dissolved Solids

Total dissolved solids (TDS) is all organic and inorganic substances, TDS can also be calculated based on the total number of anions and cations from the analysis of the chemical properties of water. According to the Appendix to the River Water Quality Standard, PP No. 22 of 2021, the total dissolved solids (TDS) allowed is 1000 mg/L. TDS obtained from measurements in the field is in the range from 84.32 to 92.12 mg/L, this value is less than 1000 mg/L and is still considered good and proper for the health of the human body.

4.2 Analysis of Chemical Properties of Water Quality in Cikapundung Watershed

a. Heavy Metal

Heavy metals are a group of metal elements that can be categorized as dangerous if they enter the body of living things. Heavy metals when found in very low concentrations will be referred to as trace metals. These metals are commonly found in aquatic environments polluted by sewage. Metals based on their toxicity in the Cikapundung watershed are divided into three groups,

1) High toxicity, exhibited by Zn metal. Zn metal based on measurements has a concentration value of 0.46 to 0.54 mg/L. Exceeding the standardized grace based on the River Water Quality Standards Attachment PP No. 22 of 2021.
2) Moderate toxicity, exhibited by metal Ni. Ni metal based on measurements has a concentration value of 0.07 to 0.08 mg/L. Exceeding the standardized grace based on the River Water Quality Standards Attachment PP No. 22 of 2021.
3) Low toxicity, indicated by Fe metal. Fe based on measurements has a concentration value of 0.49 to 0.66 mg/L.

The content of sulfate concentration ranges from 7.49 to 11.64 mg/L based on the River Water Quality Standard Attachment PP No. 22 of 2021. In addition, nitrogen content is one of the important *nutrients* needed by living things, especially in waters. Nitrogen when in the water will turn into several compounds. These compounds can be formed in ammonia, nitrite and nitrate. Ammonia ($NH3_{)}$ occurs naturally in waters as a result of the breakdown of organic and inorganic components derived from the excretion of organisms, reduction of nitrogen gas by microorganisms or gas exchange with the atmosphere. Naturally, it can turn into nitrite and nitrate in the nitrification process.

Nitrite (NO_2^-) is an intermediate compound of the nitrification process. Nitrite levels in waters naturally have low concentrations, because ammonia is converted to nitrite by nitrifying bacteria, nitrite will quickly be oxidized to nitrate compounds. Nitrate (NO_3^-) is a nitrogen compound that is commonly found in waters. Besides naturally occurring, ammonia, nitrite and nitrate can appear in water bodies as a result of the disposal of plantation, agricultural, livestock and industrial waste. In the study area, the nitrite concentration ranged from 1.68 to 2.76 mg/L and the nitrate concentration ranged from 11.99 to 13.29 mg/L. Where the concentration exceeds the standard that has been set according to the River Water Quality Standard Attachment PP No. 22 of 2021. If there is an increase in nutrient levels in the water, it causes damage to the organisms in it. Thus, the water contained in the Cikapundung watershed is not feasible based on the established river water class quality standards, especially for class 1 and 2 designations.

b. Ionic Equilibrium

Based on the results of the quality of the chemical properties of water derived from samples of the Cikapundung watershed obtained, an anion and cation content analysis will be carried out. Analysis of the chemical properties of water quality using the calculation of ion balance (*ion balance*). The purpose of the ionic equilibrium analysis is to state that all solutions have neutral properties, the calculation of ionic equilibrium is carried out by converting all major anions and cations in the water sample from mg/L units to meq/L, the calculation results can be seen in summary Table 2.

Table 2. Conversion results from mg/L to meq/L

Ion		Molar Mass	Valence	Water sample (meq/L)		
				CKD-01	CKD-02	CKD-03
CATION	Fe^{3+}	55.84	3	0.030	0.026	0.035
	Ca^{2+}	40.08	2	0.730	0.825	0.866
	Mg^{2+}	24.30	2	0.398	0.419	0.421
	Na^{+}	22.99	1	0.327	0.367	0.407
	K^{+}	39.10	1	0.099	0.113	0.116
	Li^{+}	6.94	1	<0.001	<0.001	<0.001
	Ni^{2+}	58.69	2	0.003	0.002	0.002
	Cu^{2+}	63.55	2	0.007	0.008	0.009
	Zn^{2+}	63.41	2	0.014	0.015	0.017
ANION	F^{-}	17,00	1	0.066	0.068	0.070
	Cl^{-}	35.45	2	0.226	0.238	0.259
	SO_4^{2-}	96.06	1	0.156	0.214	0.242
	HCO_3^{-}	61.02	1	0.958	0.920	0.915
	NO_3^{-}	62.01	1	0.193	0.210	0.214
	NO_2^{-}	46.01	1	0.037	0.059	0.060

After unit conversion, the ion balance calculation will be carried out to determine the quality of the sample for water quality analysis. Acceptance criteria for good and clean water sample quality are used for the calculation of hydrochemical analysis. The following are the results of the calculation of the ion balance (Table 3). All samples have anion number of more than 10, this number includes an acceptable percentage of 5%. Because the results of the ion balance of each sample are still below 5%, therefore all samples are feasible and classified as very good for use in hydrochemical analysis.

Table 3. Ionic Equilibrium Results

Category	CKD-01	CKD-02	CKD-03
Cation	1.61	1.78	1.87
Anions	1.64	1.71	1.76
Difference	0.03	0.07	0.11
%Difference	0.89	1.95	3.09

Table 4. Input results for diagrams

	Element	Unit	CKD-01	CKD-02	CKD-03
CATION	Ca^{2+}	%	45.37	46,48	53.88
	$Na^{+}+K^{+}$	%	26.51	27.04	32.51
	Mg^{2+}	%	24.76	23.60	26.16
ANION	Cl^{-}	%	13.82	13.92	15.84
	SO_4^{2-}	%	9.53	12.51	14.80
	$HCO_3^{-}+CO_3^{2-}$	%	58.53	53.88	55,90

4.3 Hydrochemical Analysis of Cikapundung Watershed

a. Piper Chart

The piper diagram is the most important method in the genetic study of groundwater systems, it is very effective in analyzing data separation for the source of dissolved constituent elements in groundwater, changes or modifications in the properties of water passing through an area or system, as well as its relationship to geochemical problems.

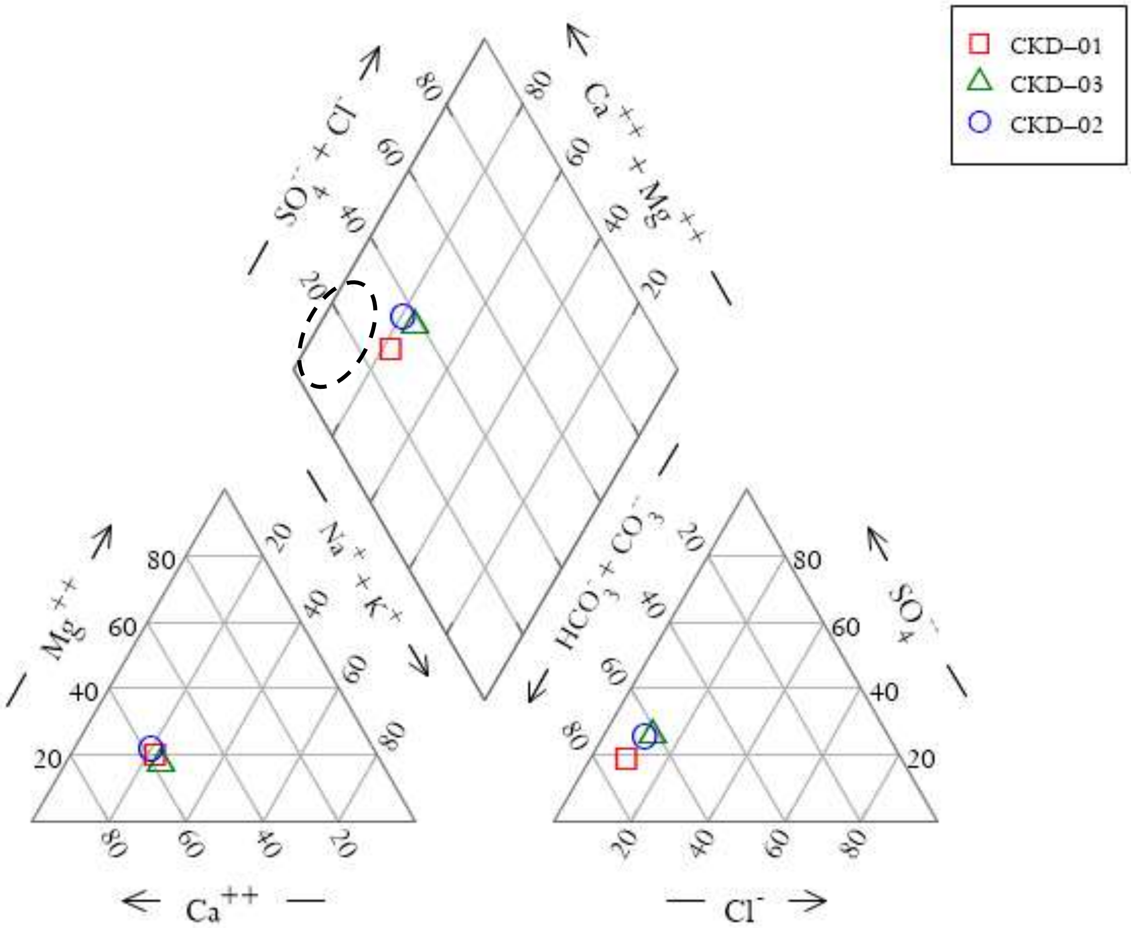

Figure 4. *Results of Piper Diagrams in the Cikapundung Watershed*

$_3$ samples taken from the Cikapundung watershed is Ca-HCO3 water . Ca – HCO $_3$ water is shallow water or natural groundwater. It can also be seen in the triangle below the left or the cation triangle, the results of the plot of the 3 samples show that water is a mixture of the types of Ca, Mg and Na - K. In addition, the results of the plot of the 3 samples in the anion triangle show that the water from the sample is a water type HCO $_3$ or type of bicarbonate water which is indicated to come from weathering of rock and mineral materials close to the surface.

b. Durov Chart

Durov diagrams have advantages compared to piper diagrams, especially in displaying images and how to understand the process of water occurrence. Durov classified water into 9 types depending on the percentage of dominant cations and anions contained in the main elements in water. Percentage of cations-anions maximum 50% and minimum 0%. The X axis is the cation axis and the Y axis is the anion. In Figure 5, the research locations are grouped into the 3rd type of water, namely water which is generally formed from ion exchange where the dominant cation can be Ca. The cation diagram on the lower left states that the sample is of *intermediate type water* . The anion diagram above states that the sample is $_{HCO3}$ type water or bicarbonate type water.

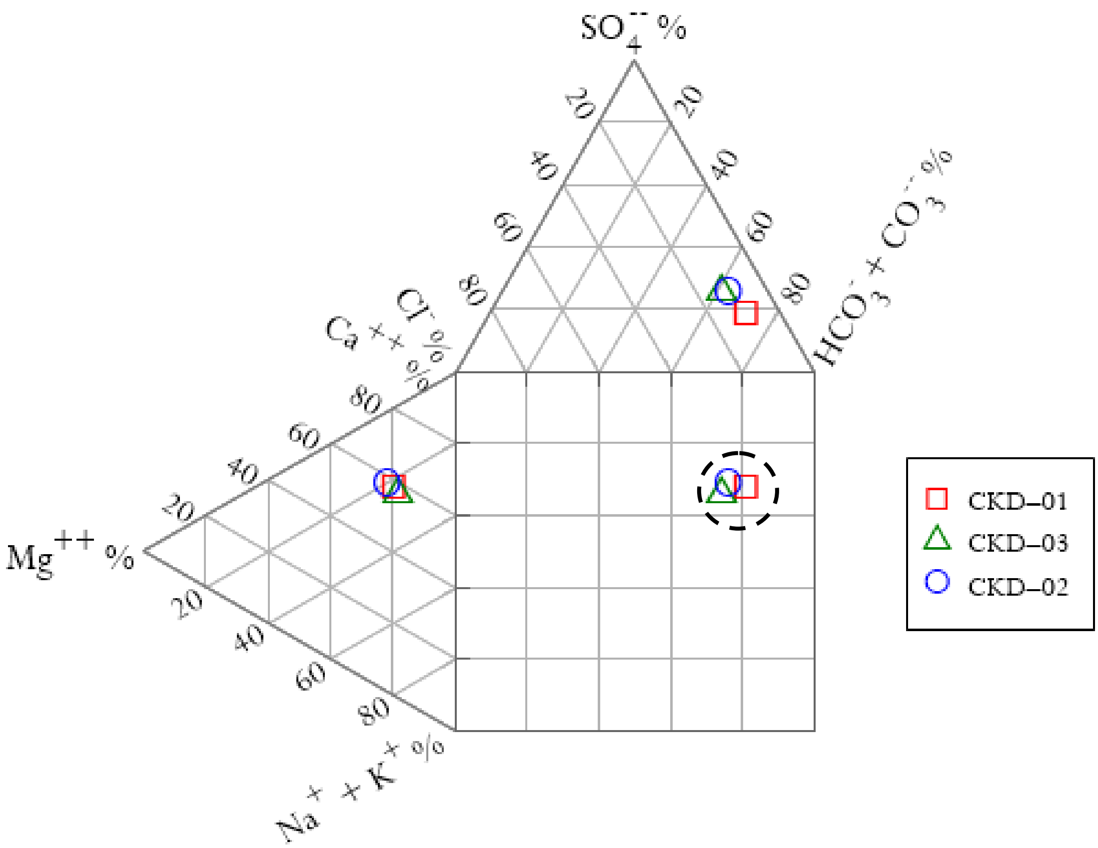

Figure 5. *The results of the durov diagram in the Cikapundung watershed*

c. Stiff Diagram

The stiff diagram can be used to relate or correlate groundwater quality. The stiff diagram also provides an illustration of the concentration ratio of the individual samples. This diagram uses four parallel horizontal axes and a vertical axis which is used to compare the chemical composition of water based on the direction of flow. Four cations are *plotted* on each axis to the left of the zero point and four anions to the right. The relationship between the points of cations and anions gives a closed *polygon or pattern.* Based on the resulting patterns, the development of these ions in groundwater can be interpreted. Figure 6 shows an illustration that SO4 ions are not significant in the study area. The Na+K, Ca and Mg ions are the most important cations. The HCO_3 +CO_3 ion is the most dominant anion.

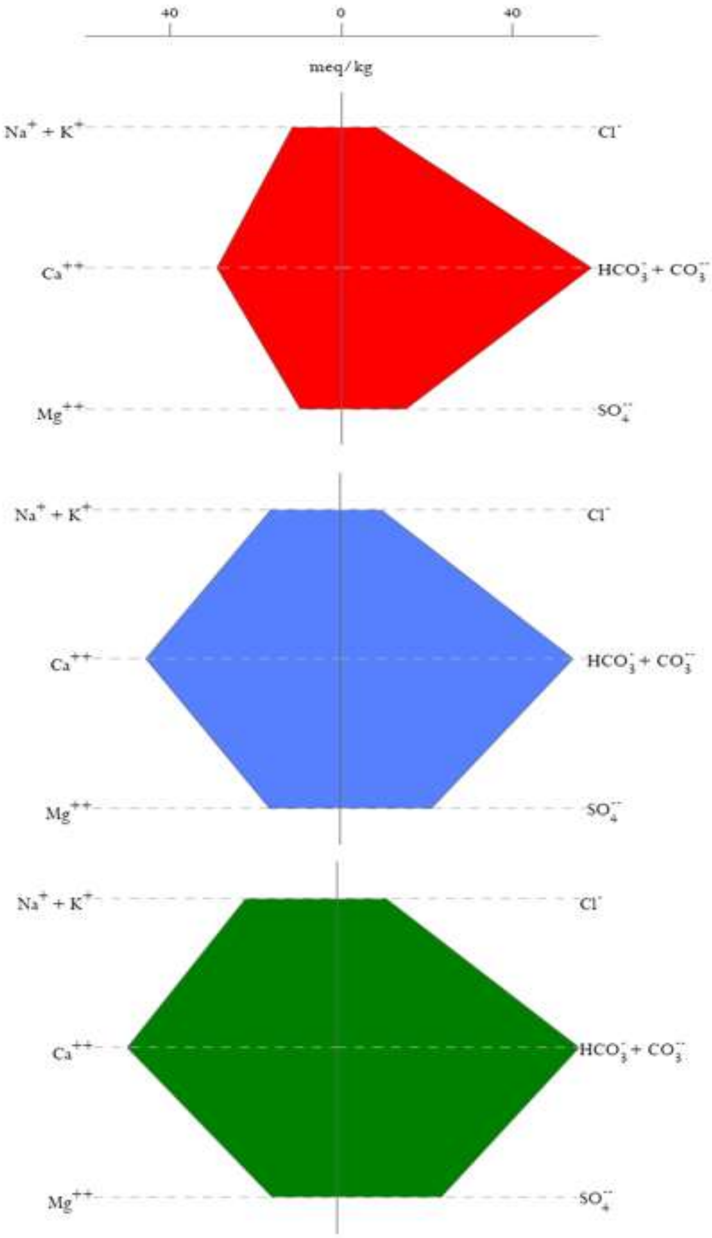

Figure 6. *The Results of the Stiff Diagram in the Cikapundung Watershed*

V. Conclusion

5.1 Conclusions

1. Pollution that occurs continuously will cause changes in the parameter values of physical and chemical properties of water quality in the Cikapundung watershed. The process that occurs in the Cikapundung watershed experiences dilution by rainwater which has a fairly high intensity in the city of Bandung.
2. Based on the results of the parameters of the chemical properties of the Cikapundung watershed associated with the River Water Quality Standards contained in the appendix of PP No. 22 of 2021, there are several elemental parameters that exceed the predetermined quality standards, so they are considered unfit to be classed for purposes 1 and 2, unless there is special or further processing for such use.
3. Based on the hydrochemical results of the water in the Cikapundung watershed, the water belongs to the type dominated by Ca-HCO_3^- based on the piper diagram, which is shallow water or natural water. Bicarbonate water comes from the weathering of rock and mineral materials close to the surface. This type is based on the Durov grouping, which is an intermediate type formed as a result of ion exchange. This is also evidenced by the stiff diagram elaboration which groups the dominant cation as Ca^+ (alkaline earth) exceeding the content of Na^+ (alkali). And where the weak acid (HCO_3^-) exceeds the strong acid.

5.2 Suggestions

1. It is necessary to add water quality parameters, especially chemical parameters to explain and show the level of pollution from anthropogenic activities.
2. It is necessary to study macroinvertebrates in the waters, and it should be done regularly to see the condition of the aquatic environment on a regular basis.

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