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Hydrogeochemical assessment of groundwater and surface water in Pomalaa District, Kolaka Regency, Southeast Sulawesi

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Abstract. Pomalaa is one of the area mining activities that significantly impact water quality due to increased concentrations of major elements. The research objective to analyze hydrogeochemical processes in groundwater and surface water in Pomalaa. The hydrogeochemical process is important to identify and control the process of groundwater and surface water interaction with minerals. The method used is geological and hydrogeochemical analysis based on the major elements. Sampling used random sampling. The primary data included 20 laboratory test samples and 3 drill log data. The secondary data included regional geological data. The Processing was conducted using RockWorks software and presented through the Kurlov Classification, Durov Diagram, Trilinear Piper Diagram, and Schoeller Diagram. The results of the Kurlov Classification and The Schoeller have shared a high cation content in Calcium and Magnesium and a high anion in Chloride and Sulfate. The high cation indicates geological formations contain Calcium and Magnesium. The high anion indicates rocks originating from the oceanic crust, formed due to high pressure and temperature, then exposed to the earth's surface due to tectonism. The Piper Diagram results show that the water is classified as alkaline earth water with higher alkaline content, predominantly Sulfate or Chloride. The Durov Diagram is classified as simple dissolution or mixing. The geological analysis results are consistent with the hydrogeochemical analysis, and the area shows the interaction between rocks and water in the study area. This research is important to provide information on geological water quality and hydrogeochemical analysis in Pomalaa.

1 Introduction

Groundwater is a crucial natural resource for human life, ecological stability, and economic development [1]. The quality of water refers to its characteristics, including the presence of living organisms, energy, substances, and other components [2]. The classification of groundwater quality is determined by analyzing its chemical composition and the hydrogeochemical processes [3]. Based on Clarck [4], it is evident that various chemical processes, including cation exchange, salt dissolution, and groundwater and saltwater mixing influenced the hydrogeochemical of groundwater.

The quality and quantity of groundwater are determined by the geological formation of each rock mineral, which contains various elements and chemical compounds [2,5]. Groundwater interacting with rocks causes geochemical processes that change the chemical makeup of the water and its diverse chemical characteristics [6,7]. Mining activities can also affect groundwater quality [8].

Pomalaa is abundant in natural resources, which has led to the establishment of mining activities in the area.[9]. These activities potential to modify hydrogeological and surface conditions [10] and contribute to groundwater pollution including heavy metals [11]. Mining activities have the potential to affect the quality of surface water by raising water turbidity and increasing concentrations of major ions and trace elements.[12].

Surface water and groundwater provided a deeper understanding of potential variations in water quality caused by land use and geology [13]. Characterizing the hydrochemical properties of a water body is an effective assessment of the characteristics of the aquatic environment and the associated hydrogeochemical processes [14]. The assessment of water quality can be accomplished through the analysis of geochemical data and the testing of samples [15].

The Kurlov classification and the Piper Diagram are valuable tools for determining groundwater type, cation, anion, and facies, which are important factors to consider when evaluating the suitability of groundwater as drinking water [15]. Research utilizing hydrogeochemical methods to assess water quality in the region remains limited. Previously, Okto, A., et al. [9] conducted study on groundwater quality around mining sites in Kolaka Regency using the Pollution Index method. However, there were limited studies utilizing geological and hydrogeochemical analysis methods.

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The study aims to contribute novel insights into water quality through geological and hydrogeochemical analytical methods that are not currently documented in existing literature. The research objective is to analyze hydrogeochemical processes in groundwater and surface water in Pomalaa. Hydrogeochemical analysis can provide information on the classification of groundwater and surface water quality and the interaction of groundwater, surface water, and lithology in Pomalaa District. The hydrogeochemical process is important to identify and control the process of groundwater interaction with minerals in the aquifer [16]. The research used geological and hydrogeochemical analysis presented through the Kurlov Classification, Durov Diagram, Trilinear Piper Diagram, and Schoeller Diagram.

2 Method

2.1 Research area

The research site was located in the Pomalaa District, Kolaka Regency, Southeast Sulawesi. Pomalaa District is at an elevation of 380 meters which has varied terrain [17]. The research was conducted at geographical coordinates 4°10'42" S - 4°15'10" S and 121°38'3" E - 121°41'6" E. Data processing, interpretation, analysis, and report preparation were conducted in the office PT. Indra Karya (Persero) Survey & Investigation Division. The data collection period is from January 2021 to January 2024.

2.2 Data Acquisition

This research was conducted in four stages (Fig. 1): preparation, collection, processing, and article preparation. The first stage is preparation, which includes determining the theme, conducting a literature review, and formulating the problem. The second stage is data collection. Primary data are groundwater samples in deep wells, monitoring wells, surface water, and drill log data. Secondary data is geological data of the study area.

Sampling uses random sampling. Groundwater samples were taken in Pomalaa from 5 deep wells, 6 monitoring wells, and 9 surface water samples, totaling 20 (Table 1). Monitoring well samples were taken from 2 monitoring wells with 3 sampling times, making 6 samples. The samples were taken along the Oko River (Fig. 2). 3 samples are below the detection limit. Sample testing was conducted at the Mathematics and Natural Sciences Laboratory, Halu Oleo University, and the Environmental Agency Laboratory, Kolaka, Southeast Sulawesi. These two laboratories were chosen because they were the closest to the study area, thus avoiding damage to the samples. Drill log data was obtained from the engineering analysis of PT. Indra Karya (Persero) Survey and Investigation Division.

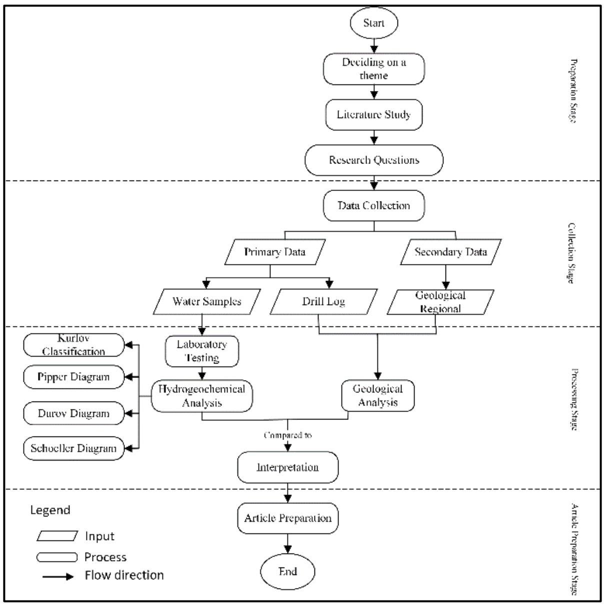


Fig. 1. Research flowchart.

The third stage is processing, including testing groundwater and river water samples in the laboratory. Test results based on major element content were analyzed using hydrogeochemical analysis through Rockworks software. The major elements are cations and anions. Cations included: Calcium (Ca^{2+}), Potassium (K^{+}), Magnesium (Mg^{+}), and Sodium (Na^{+}). Anions included Sulfate (SO_4^{2-}), Chloride (Cl-), Carbonate (CO_3^{2-}), and Bicarbonate (HCO_3^{-}). The Rockworks software is used for processing data, and the samples are converted to meq/l.

The results of hydrogeochemical analysis, which includes dominant cations and anions, are compared with the results of geological analysis, such as dominant cations and anions obtained from the types of rocks found in geological formations. The results of geological and hydrogeochemical analysis are all compared. It is crucial to compare these two sets of data as geological analysis relies heavily on accurate data sources. These sources include drill logs sampled from the subsurface and research conducted by previous geologists on geological maps. The final stage is preparing the article.

Based on (Table 1) shows the highest Calcium cation was taken from surface water in sample EWO-02 at 125.60 mg/l. The highest Potassium was taken from a deep well in sample A1 at 0.9472 mg/l. The highest Magnesium was taken from surface water in sample OKO-01, at 138.72 mg/l. The highest Sodium was taken from a deep well in sample ASM-E-1B at 35.7 mg/l.

The highest Sulfate content in surface water was found in sample OKO-01 at 18.90 mg/l. Sample EWO2-02 had the highest Chloride content at 119.92 mg/l. Carbonate and Bicarbonate were only present in samples ASM-B-1 and ASM-E-1B. The drilling data includes three points: Drill Point A (125m), Drill Point B (203m), and Drill Point E (183m), and mainly consists of peridotite, serpentinite, and basalt.

Table 1. Test sample data based on major elements.

No	Sample Code	Major Element							
		Kation				Anion			
		Ca^{2+} (mg/l)	K^{+} (mg/l)	Mg^{+} (mg/l)	Na^{+} (mg/l)	SO_4^{2-} (mg/l)	Cl- (mg/l)	CO_3^{2-} (mg/l)	HCO_3^{-} (mg/l)
	Deep Well								
1	ASM-B-1	76.1	0.029	38.9	30.6	bdl	1.6	1.86	3.48
2	ASM-E-1B	80.3	0.034	40.6	35.7	bdl	1.8	2.6	4.1
3	Well A1	18.1033	0.9472	2.1183	10.072	1.135	4.998	-	-
4	Well B-2	21.0051	0.4098	1.8022	14.0255	bdl	9.397	-	-
5	Groundwater (D-1)	30.7	0.0122	0.0282	0.1712	4.1	0.035	-	-
	Monitoring Well								
6	Well (MW1-01)	17.4571	0.7221	2.0023	7.0425	1.589	5.99	-	-
7	Well (MW1-02)	14.7665	0.034	1.6202	35.7	1.190	2.999	-	-
8	Well (MW1-03)	23.3655	0.0219	1.2768	10.0266	3.036	10.99	-	-
9	Well (MW2-01)	28.60	0.1966	1.8665	15.8700	12.80	0.85	-	-
10	Well (MW2-02)	22.80	0.0564	0.6744	7.852	10.60	0.59	-	-
11	Well (MW2-03)	30.30	0.0398	0.4622	8.1265	8.60	0.21	-	-
	Surface Water								
12	River Water (EWO2-01)	17.4032	0.8573	2.1293	10.9710	2.345	0.99	-	-
13	River EWO-02	16.8947	0.7846	2.2935	8.0237	0.297	1.799	-	-
14	EWO02-03	26.0112	0.4991	1.5201	11.3301	4.080	3.99	-	-
15	OKO-01	28.60	0.1655	138.72	32.24	18.90	1.86	-	-
16	EWO-02	125.60	0.0911	1.0072	28.70	8.60	1.80	-	-
17	OKO-02	118.50	0.0876	1.0062	36.90	0.022	2.15	-	-
18	EWO2-01	26.2655	0.4219	1.4668	11.4266	1.967	4.99	-	-
19	EWO2-02	22.0114	0.3001	1.3001	11.0102	2.34	119.92	-	-
20	EWO2-03	25.0992	0.5001	1.5202	12.1001	bdl	13.99	-	-

Note: bdl means below detection limit, Sulfate <1 (ASM-B-1 and ASM-E-1B), <0.034 (Well B-2 and EWO2-03).

3 Result and discussion

3.1 Geology of the study

The research site is in Pomalaa District, Kolaka Regency, Southeast Sulawesi. Based on the Kolaka Sheet Geological Map, as shown in (Fig. 2), Pomalaa consists of three rock formations: Ultramafic Complex (Ku), Alangga Formation (Qpa), and Langkowala Formation (Tml) [18]. However, the sampling area only covers the Langkowala Formation and the Ultramafic Complex. The Ultramafic Complex is dominated by harsburgite, dunite, wherite, serpentinite, gabbro, basalt, dolerite, diorite, meta mafic, amphibolite, magnesite and locally rodingite. The Ultramafic Complex is located in the malachite belt of the East Sulawesi Geological Mandala, which was formed during the Cretaceous period [18]. The Alangga Formation is dominated by conglomerate and sandstone [18]. Alangga Formation is a surface sediment and sedimentary rock formed in the Pleistocene Period and the Quaternary Age [18]. The Langkowala Formation is dominated by conglomerate, sandstone, shale, and local calcarenite[18]. Tml and Qpa are surface deposits and sedimentary rocks formed during the Miocene Period, the Tertiary Age [18].

An ophiolite is a section of former oceanic crust along with its underlying mantle [19]. The East Sulawesi Ophiolite Belt is an ophiolite of an imbricated oceanic segment and sedimentary rocks of the Triassic-Miocene age. The East Sulawesi Ophiolite Belt is a complex of ophiolite and plagic sedimentary rocks in Sulawesi Island's Eastern Arm and Southeast region. Ultramafic rocks are the dominant rocks in the Southeast Arm [20]. The East Sulawesi ophiolite consists of, from base to top, mantle remnants of peridotite and mafic-ultramafic that accumulate through layered to isotropic gabbro, to layered dolerite and basaltic volcanic rocks[21]. Presented by Hasria, et al. [22], the results of geochemical data interpretation indicate that the igneous rock of Waturapa, South Konawe Regency, Southeast Sulawesi are classified as ultramafic rocks (peridotite gabbro). Ultramafic rocks originate from the oceanic crust, formed due to high pressure and temperature conditions, then uplifted, and then exposed on the earth's surface due to tectonism in the oceanic crust [23].

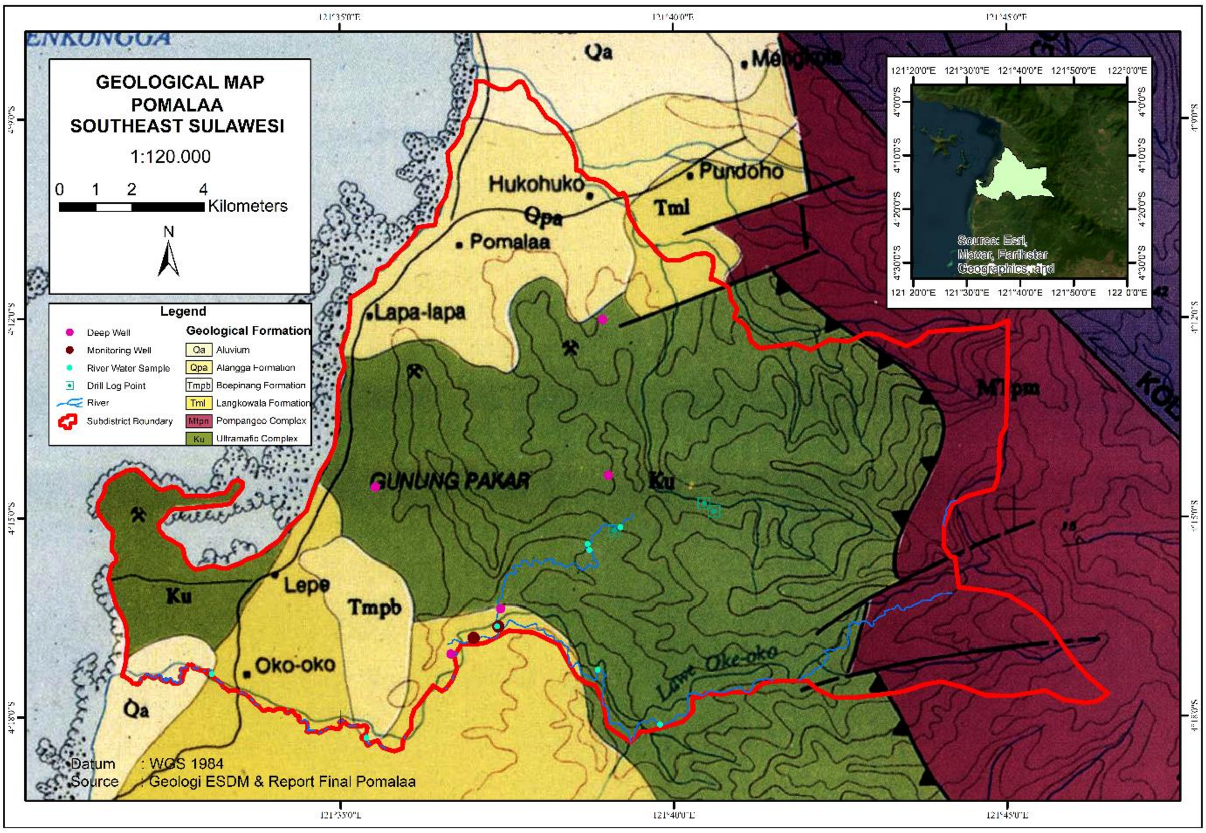


Fig. 2. Geological Map of Pomalaa [18] modified.

3.2 Geological analysis

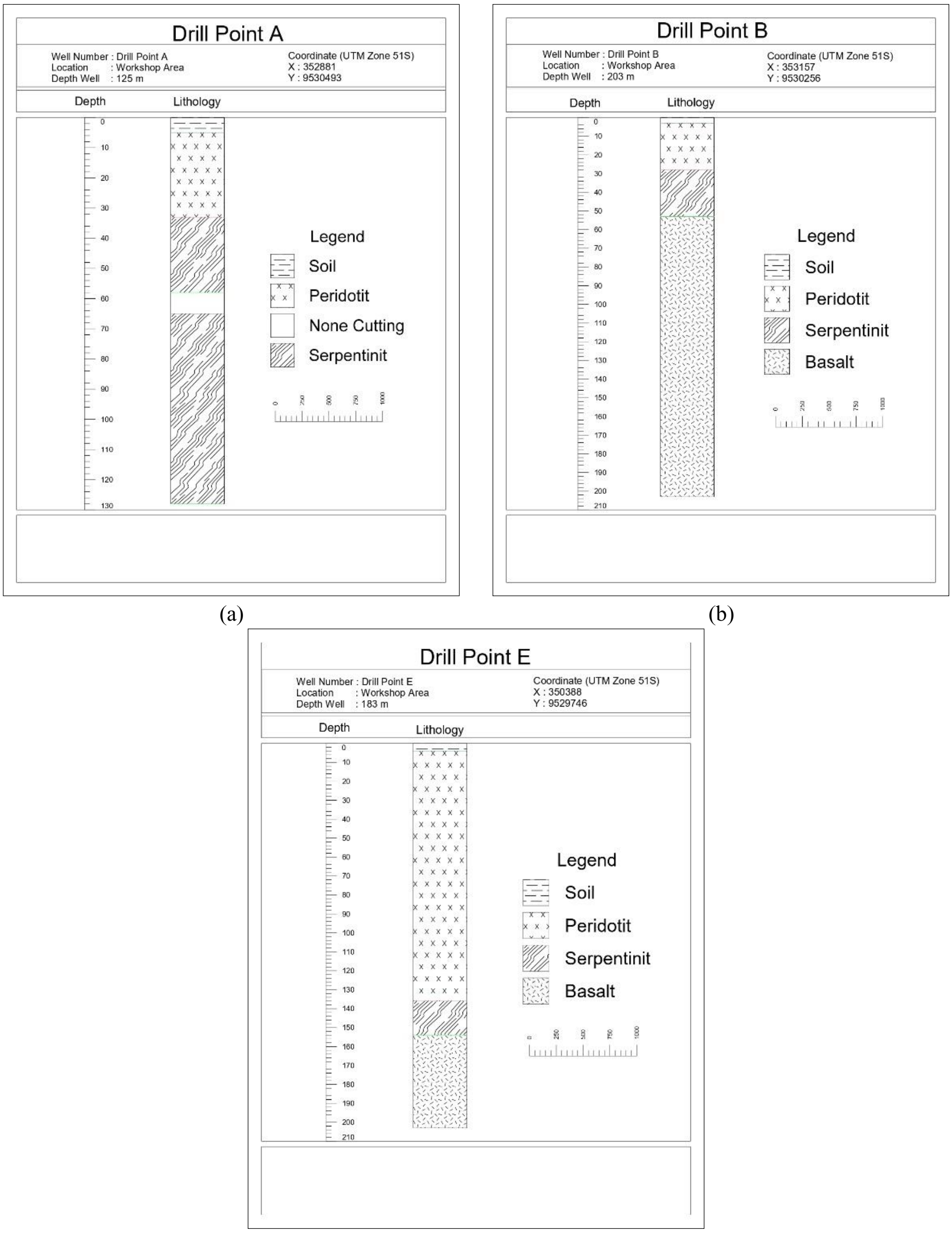
The geological analysis is based on regional geological data and drill logs. The geological formations in the deep well sampling are the Ultramafic Complex and Langkowala Formation. The Ultramafic Complex includes wells A1, ASM-1-B, and B-2. The Langkowala Formation includes Well B-1 and Groundwater (D-1). The monitoring well samples are in the Langkowala Formation, including Well (MW1-01) and Well (MW1-02).

The Ultramafic Complex is an igneous rock dominated by olivine and pyroxene mineral content [24–26]. Ultramafic rocks are rarely found on Earth's surface [25,27]. Some Ultramafic bodies found associated with sedimentary rocks and marine-deposited volcanic in the ophiolite sequence [19]. The mineral olivine ($(Mg, Fe)_2SiO_4$) has magnesium cations [25]. Olivine mineral is a group of high-temperature silicate minerals that are black to olive green in color and it is common in the igneous rock basalt and constitutes up to 50% of Earth's upper mantle [25]. The mineral pyroxene ($(Mg, Fe)_2Si_2O_6$) contains the same main cations as the mineral olivine [28].

The Langkowala Formation is a clastic sedimentary rock [29] dominated by conglomerate, sandstone, and local calcarenite shale [18]. Clastic sedimentary rocks formed from mineral fragments (clast) and rock that occurs in generation, transportation, and lithification [30]. Clastic sedimentary rocks generally contain silicate minerals (quartz and pyroxene) [31]. Quartz minerals have the chemical formula SiO_2 [25,32].

The drill log data shows that the rock formation in wells A, B, and E is Ultramafic Complex. Drill log results were obtained to a depth of 84m at an elevation of 438.86m. Depth 0 - 5 m is brownish-red soil. The depth of 5 - 33 m is peridotite rock. Peridotite rock is one of the igneous rocks in the Ultramafic Complex and almost entirely contains ferromagnesian minerals [25]. The ferromagnesian contains amounts of Iron (Fe) and Magnesium (Mg) [33]. Peridotite is composed various between iron-rich and magnesium-rich [34]. Peridotite rocks have the chemical formula $(Mg, Fe, Ca, Na, Ti)(Al, Si)_2O_6$ [35]. Peridotite can be found in the oceanic and continental crust because the magma that forms these rocks is formed in the mantle and can rise and disrupt the earth's crust above it [36].

The high Magnesium cation content in the deep wells and monitoring well water samples indicate that they comprise peridotite rocks. The depth of 33 - 128 m is serpentinite rock. Serpentinite rock is composed of serpentine minerals, a hydrous magnesium silicate that has chemical formula ($H_4Mg_3Si_2O_9$) and resulted from alteration of large bodies of peridotite [37]. Serpentinite rock is one of the metamorphic rocks formed from the metamorphose of Ultramafic rocks [38]. Serpentinite rock has the chemical formula ($(Mg, Fe)_6Si_4O_{10}(OH)_8$) [39]. These rocks are similar to peridotite rocks with a high magnesium cation content.



(a) (b)

(c)

Fig. 3. Drill Point (a) Drill Point A, (b) Drill Point B, and (c) Drill Point E.

Drill log results in well B were obtained to a depth of 203 m at an elevation of 424.66 m. Depth 0 - 3 m is brownish-red soil. The depth of 3 - 28 m is peridotite rock. Depth 28 - 53 m is serpentinite rock. Depth 53 - 203 m is basalt rock. Basalt rocks contain plagioclase feldspar, pyroxene, olivine, and magnetic minerals [40]. Basalt is from extensive lava flows on continents[25]. Plagioclase feldspar minerals have two groups, namely, albeit ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) [31,41]. Magnetite mineral has the chemical formula Fe_3O_4 [41].

The results of the drill log in well E were obtained to a depth of 84 m at an elevation of 401.21 m. The depth of 0 - 4 m is soil. Depth 0 - 4 m is brownish-red soil. Depth 4 - 136 m is serpentinite rock, and depth 136 - 154 is basalt rock. Depth 154 - 185 is serpentinite rock. Depth 185 - 200 m is serpentinite rock.

3.3 Hydrogeochemical analysis

The Kurlov method determines the name of groundwater/facies based on the milliequivalent per liter of each ion [43]. The results of the Kurlov Classification show the existence of various groundwater facies. According to Purnama, et al. [44], groundwater facies are the identification of groundwater types based on the differences and genesis of water related to soil systems and bodies. Groundwater facies in Kurlov are grouped according to the cations and anions above 30%. If there is more than one dominant cation and anion, the ion

names are sorted by percentage from high to low. The dominant cation name is mentioned first.
Table ***2***) Kurlov Classification, the beige color in each cation and anion column shows a high percentage or above 30%. The soil facies have 8 facies types, indicated by 8 different colors in sequence (Table 3). The Calcium Bicarbonate Chloride (Ca – HCO_3 – Cl) facies are present in 2 deep well samples, including wells ASM-B-1 and ASM-E-1B. Calcium Alkali Chloride (Ca – Na + K – Cl) is present in 2 deep well samples, including wells A1 and B-2, and monitoring well only (MW1-02). Calcium Sulfate (Ca – SO_4) is present in deep wells only in Groundwater (D-1). The monitoring well includes the well (MW2-02), well (MW2-03), and surface water, which is only OKO-01.

Calcium Chloride (Ca – Cl) is present in monitoring wells, including Well (MW1-01), Well (MW1-03), and river water, including River EWO-02, OKO-02, EW02-01, EW02-02, and EW02-03. Calcium Alkali Sulfate (Ca – Na + K – SO_4) is present in the monitoring well only Well (MW2-01). Calcium Alkali Sulfate Chloride (Ca – HCO_3 – SO_4 – Cl) is only present in the River Water sample (EW02-01). Calcium Sulfate Chloride (Ca – Na + K – SO_4) is only present in river water

Based on (

sample EWO02-03. Magnesium Sulfate (Mg – SO_4) is only sampled from Surface water OKO-01.

The results of the Kurlov analysis show that the 19 samples have a high content of Calcium cations. River water samples are high in Calcium due to clay minerals that have fine grain size and low density easily transported by water and also can be deposited on land by streams [32]. The distribution of Calcium Magnesium cations causes groundwater to be composed of alkali [45].

Based on Kozisek [46], high concentrations of Calcium and Magnesium or total hardness in drinking water cause corrosion, scaling, and taste of water. One of the existing samples taken in river water has a high content of Magnesium cations. The geology of the area can cause high Magnesium in river water samples. The Oko River flows through the Ultramafic Complex, the rocks contain high Calcium and Magnesium. Based on research conducted by Afriyani, et al. [3] in Lasusua, Kolaka Regency has ultramafic parent rock characteristics. The laboratory analysis results of the chemical composition of rock elements show the highest Magnesium content, weighing 19.83%, which is the main characteristic of ultramafic rocks.

Table 2. Kurlov Classification [42] modified.

Kurlov Classification

Sample id	Kation (%meq/l)			Anion (%meq/l)			Facies
	Ca	Mg	Na+K	HCO_3+CO_3	SO_4	Cl	
ASM-B-1	45.59	38.42	15.99	55.83	0.00	44.17	Calcium Bicarbonate Chloride
ASM-E-1B	45.02	37.52	17.46	56.96	0.00	43.04	Calcium Bicarbonate Chloride
Well A1	58.68	11.32	30.00	0.00	14.36	85.64	Calcium Alkali Chloride
Well B-2	57.69	8.16	34.15	0.00	0.00	100.00	Calcium Alkali Chloride
Groundwater (D-1)	99.35	0.15	0.50	0.00	98.86	1.14	Calcium Sulfate
Well (MW1-01)	64.04	12.11	23.85	0.00	16.37	83.63	Calcium Chloride
Well (MW1-02)	30.40	5.50	64.10	0.00	22.65	77.35	Calcium Alkali Chloride
Well (MW1-03)	68.28	6.15	25.57	0.00	16.94	83.06	Calcium Chloride
Well (MW2-01)	62.71	6.75	30.55	0.00	91.75	8.25	Calcium Alkali Sulfate
Well (MW2-02)	74.06	3.61	22.33	0.00	92.99	7.01	Calcium Sulfate
Well (MW2-03)	79.39	2.00	18.61	0.00	96.80	3.20	Calcium Sulfate
River Water (EWO2-01)	56.31	11.36	32.33	0.00	63.62	36.38	Calcium Alkali Sulfate Chloride
River EWO-02	60.20	13.47	26.33	0.00	10.86	89.14	Calcium Chloride
EWO02-03	67.31	6.48	26.21	0.00	43.01	56.99	Calcium Sulfate Chloride
OKO-01	10.02	80.11	9.87	0.00	88.24	11.76	Magnesium Sulfate
EWO-02	82.46	1.09	16.45	0.00	77.91	22.09	Calcium Sulfate
OKO-02	77.77	1.09	21.14	0.00	0.75	99.25	Calcium Chloride
EW02-01	67.60	6.22	26.18	0.00	22.54	77.46	Calcium Chloride
EW02-02	64.92	6.32	28.75	0.00	1.42	98.58	Calcium Chloride
EW02-03	65.36	6.53	28.12	0.00	0.00	100.00	Calcium Chloride

Note: Beige color means cation and anion shows a high percentage or above 30%.

High Bicarbonate anions are due to the presence of carbonate minerals in the aquifer associated with Bicarbonate buffering so that water can dissolve calcite, dolomite, and other carbonate minerals in groundwater [47]. The high Chloride anion is due to these rocks originating from the oceanic crust, formed due to high pressure and temperature conditions, and then exposed to the earth's surface due to tectonism [23]. Groundwater high Sulfate can be caused by the dissolution, atmospheric deposition, and anthropogenic sources including mining activities [48]. The dominant facies contain high cations compared to anions. This indicates the presence of chemical reactions that cause rock decomposition and leaching of minerals into the water [49].

Table 3. Kurlov classification results.

No	Sample id	Facies
1	ASM-B-1	Calcium Bicarbonate Chloride
	ASM-E-1B	Calcium Bicarbonate Chloride
2	Well A1	Calcium Alkali Chloride
	Well B-2	Calcium Alkali Chloride
	Well (MW1-02)	Calcium Alkali Chloride
3	Sumur (MW2-01)	Calcium Alkali Sulfate
4	River Water (EWO2-01)	Calcium Alkali Sulfate Chloride
5	Well (MW1-01)	Calcium Chloride
	Well (MW1-03)	Calcium Chloride
	River EWO-02	Calcium Chloride
	OKO-02	Calcium Chloride
	EWO2-01	Calcium Chloride
	EWO2-02	Calcium Chloride
	EWO2-03	Calcium Chloride
6	Groundwater (D-1)	Calcium Sulfate
	Well (MW2-02)	Calcium Sulfate
	Well (MW2-03)	Calcium Sulfate
	EWO-02	Calcium Sulfate
7	EWO02-03	Calcium Sulfate Chloride
8	OKO-01	Magnesium Sulfate

3.3.1 Durov diagram

The Durov diagram determines the ratio of cations and anions in water such as the Piper Diagram. However, this diagram has a rectangular plot This diagram uses milliequivalent per litre. The results of the Durov diagram show 3 monitoring well samples and 6 river water samples, making a total of 9 wells included in the calcium type. Monitoring wells include Well (MW1-01), Well (MW2-02), and Well (MW2-03). River water includes EWO02-03, EWO-02, OKO-02, EWO2-01, EWO2-02, and EWO2-03. According to the regional geological analysis, the monitoring wells are located in the Langkowala Formation rock formation, which has a high Calcium content. Calcium comes from the dissolution of rocks with dominant lime [50]. Limestone is a sediment that contains marine organisms that have died and turned into Calcium carbonate. This rock results from accumulation and sedimentation that occurred thousands of years ago and formed massive rocks with a yellowish-white to brownish colo

The rectangular field is classified as simple dissolution or mixing. In the deep well, there are 2 samples. In the monitoring well, 3 samples and surface water, there were 2 samples for a total of 7. Deep wells include ASM-B-1 and ASM-E-1B. Monitoring wells include Well (MW2-01), Well (MW2-02), and Well (MW2-03). Surface water included OKO-01 and EWO-02. The well samples show mixing, indicating that the circulation has mixed with the surface conditions [51]. This condition can occur because groundwater undergoes a mixing process in several aquifers [52].

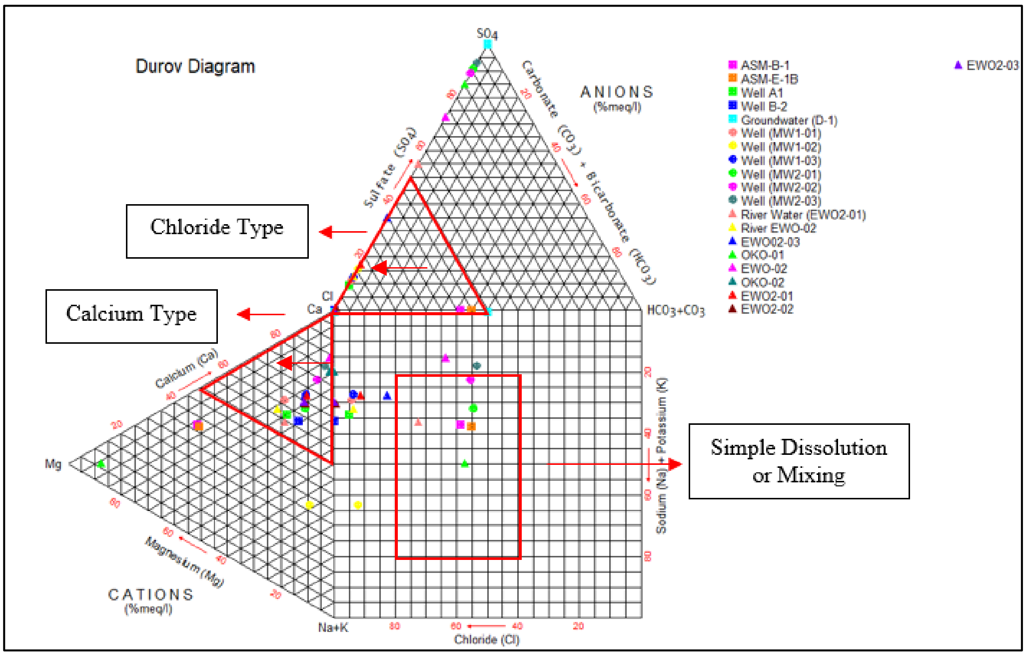


Fig. 4. Durov Diagram [42] modified.

3.3.2 Piper diagram

The Piper Diagram is a chart to represent the chemical facies of a set of water samples [53]. The classification used in this diagram is the classification of Piper [54] modified by Furtak and Langguth (1967). The classification in the diagram uses the dominant cation-anion group concerning its position to determine the type of water quality. Cations and anions are plotted separately on the left and right-side triangles and then drawn perpendicular to the center planes.

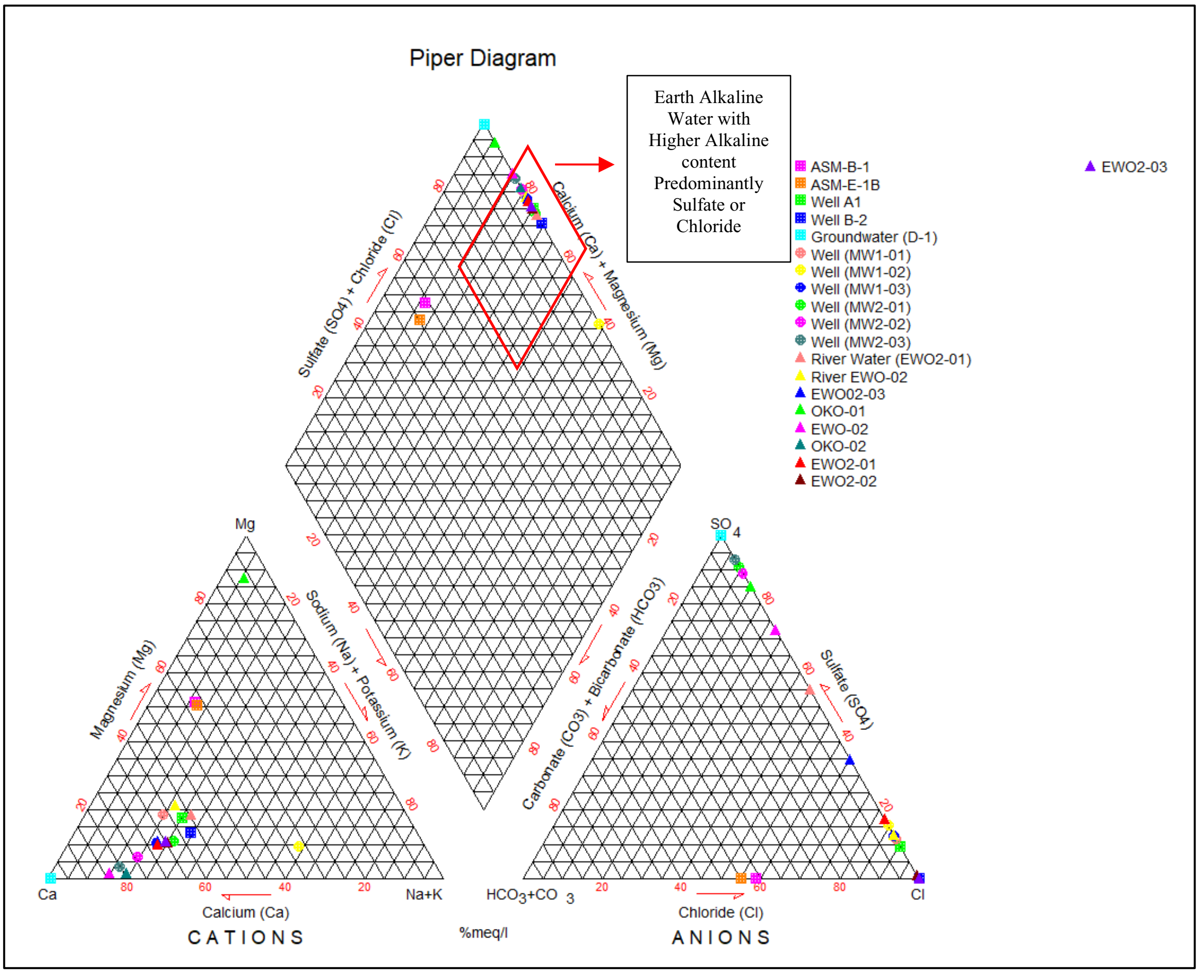


Fig. 5. Piper Diagram [54] modified.

The Kurlov Classification and Durov Diagram results previously showed Calcium, Sulfate, and Chloride dominant results. The Piper Trilinear Diagram results also show the same results on the left and right-side planes. The center plane shows that the groundwater is classified as alkaline earth water with higher alkaline content, predominantly Sulfate or Chloride. This groundwater has a very high alkaline content with dominant Sulfate and Chloride content. The lithology of the aquifer influences the groundwater facies. The distribution of Calcium and Magnesium cations causes groundwater to be composed of alkaline earth water in volcanic areas [45]. Alkaline earth indicates the dissolution of carbonates such as limestone by carbonic acid, which is the main source of Calcium in the region [55]. These facies show groundwater mixed with sodium minerals and rock interactions with clay mineral-rich content from the dominant alluvium layer of Chloride and Sulfate anions [45].

The high Chloride content indicates that groundwater interacts with rocks originating from the oceanic crust formed due to high pressure and temperature conditions, then exposed at the earth's surface due to tectonism in the oceanic crust [23]. The high Chloride content in groundwater is rarely of rock origin, so its presence in groundwater is only associated with pollution and seawater influences [56]. The high Sulfate and Chloride-dominated groundwater content is due to high evaporation, indicating that the area has been influenced by seawater in the past [3]. This type can be found in 2 deep well samples, 3 monitoring well samples, and 7 surface water samples, totaling 12. Deep wells include samples of Well A1 and Well B-2. Monitoring wells include samples of Well (MW2-01), Well (MW2-02), and Well (MW2-03). Surface water includes samples of River Water (EWO2-01), River EWO-02, EWO-02, OKO-02, EWO2-01, EWO2-02, and EWO2-03. In addition, this type can be found in the Ultramafic Complex, which shows part of the East Sulawesi Ophiolite formed from the limestone age, Mesozoic era, where at that time, Sulawesi was still connected to Gondwana, which caused shallow sediments.

3.3.3 Schoeller diagram

In Schoeller diagrams, the concentration of each ion is displayed on a vertical and logarithmic vertical scale that can plot a broader range of concentrations to show where the concentration is relevant, for example, about ion exchange processes [57]. The results showed that 1 sample had a high Magnesium content in sample OKO-01. One sample showed a high content of chloride in sample EWO2-02. The high Chloride content indicates that groundwater interacts with rocks originating from the oceanic crust formed due to high pressure and temperature conditions, then exposed at the earth's surface due to tectonism in the oceanic crust [23].

2 samples from the deep well have almost the same amount of Calcium and Magnesium, namely, samples ASM-B-1 and ASM-E-1B. At the same time, samples EWO-02 and EWO-03 have high Calcium content and are almost the same. In addition, 14 samples show the same pattern, where the results of cation and anion analyses have almost the same value. The well samples include Well A1, Well B-2, Groundwater (D-1), Well (MW1-01), Well (MW1-02), Well (MW1-02), Well (MW2-01), Well (MW2-02), Well (MW2-03), River Water (EWO2-01), River EWO-02, EWO02-03, EWO2-01, and EWO2-03. The geology of the area can cause high Magnesium in river water samples. The Oko River flows through the Ultramafic Complex, the rocks contain high Calcium and Magnesium.

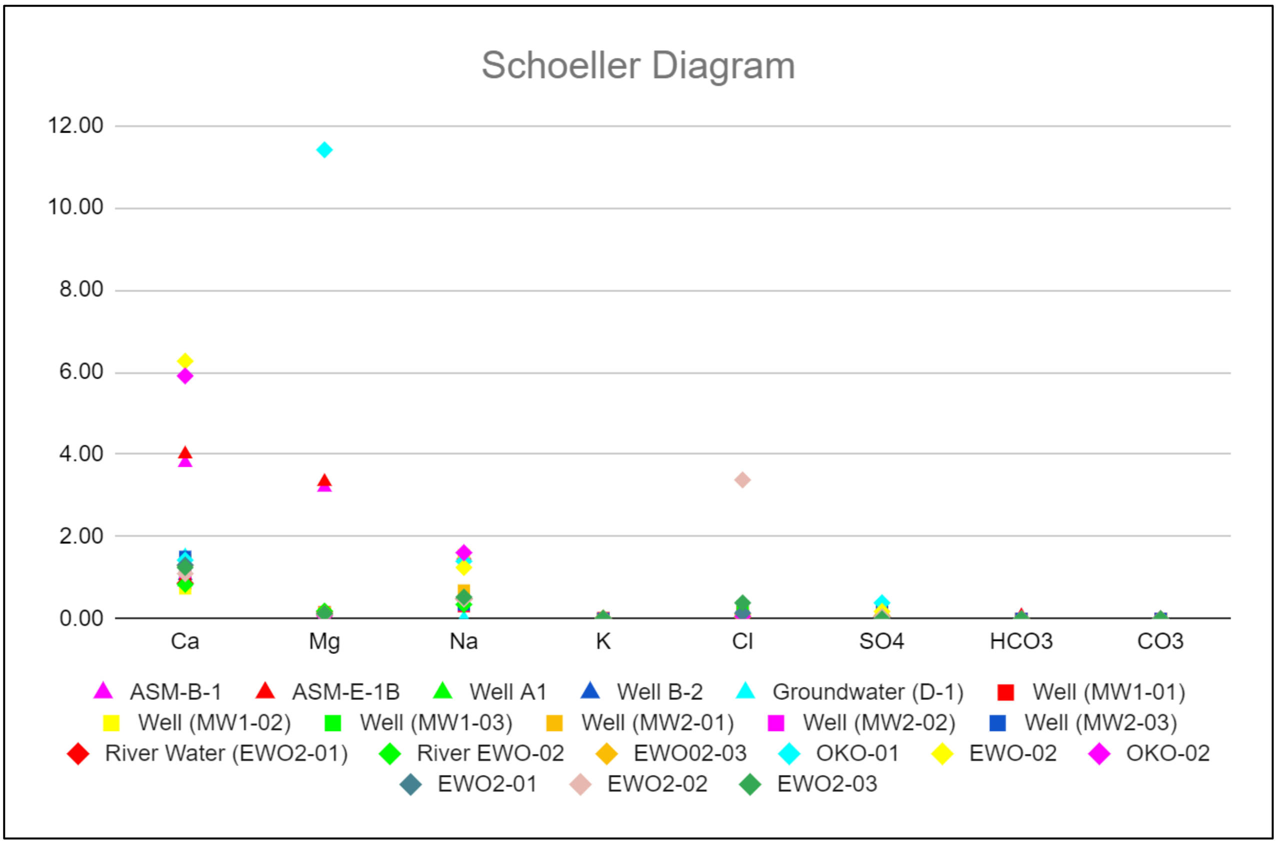


Fig. 6. Schoeller Diagram [58] modified.

3.4 Comparison of geological analysis and hydrogeochemical analysis

The previous geological analysis showed consistency with the hydrogeochemical analysis. The regional geological data and drill log data show that the dominant rocks contain cations of Magnesium, Calcium, and anion Sulfate, Chloride. The regional geology shows that the study site is in the Ultramafic Complex geological formation and the Langkowa Formation. Both formations have a high content of magnesium and magnesium cations. This is also shown in the hydrogeochemical analysis.

Drilling log data confirms the results of the hydrogeochemical analysis. All three drill logs are dominated by peridotite, serpentinite, and basalt rocks derived from the Ultramafic Complex. Based on geological analysis, serpentinite and basalt rocks contain magnesium cations, and peridotite rocks contain magnesium and calcium. The geological analyses consistently describe the hydrogeochemical processes of groundwater and surface water at the study site. This indicates the interaction between rock and water in the area. This study has several limitations. Firstly, the sample size was limited. Secondly, the surface water samples do not have exact coordinates. Finally, this study only focuses on hydrogeochemical processes in the study area.

4 Conclusions

The geological analyses consistently describe the hydrogeochemical processes of groundwater and surface water at the study site. This indicates the interaction between rock and water in the area. The high calcium and magnesium content is consistent with regional geological data and drill log data, which show that the rocks in the area are rich in calcium and magnesium. High Calcium and Magnesium or total hardness in drinking water caused corrosion, scaling, and taste of water. The chloride content indicates that the rocks originated from oceanic crust that was later exposed to the earth's surface. The research contributes knowledge on water quality through geological and hydrogeochemical analysis that is currently not documented in the existing literature, especially in Pomalaa as a mining area.

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