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|Research Article

Hydrogeochemical Analysis to Identify Potential Groundwater Characteristics in the Jayapura Region

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ABSTRACT

Hydrogeochemistry and stable isotope $\delta^{18}O$ and $\delta^{2}H$ are chemical methods used to understand the chemical process of water flows in the aquifer. This study aims to identify the characteristics of groundwater and surface water in the Jayapura area. Water samples are collected from 87 points throughout the study area. The results of hydrogeochemical analysis on the main ions presented in the piper diagram show that the dominant water type is Ca/Mg-HCO_3^-. In addition, other water types such as Ca-HCO_3^-, Na-HCO_3^-, Mg-SO_4^{2-}, Ca-Cl, and Na-Cl are found. Rainwater is used as the reference line in the diagram, referred to as LMWL (local meteoric water line), with the equation H = 7.019$\delta^{18}O$ + 7.5162 and a correction coefficient of 0.997. Stable isotope analysis of $\delta^{18}O$ and $\delta^{2}H$ in groundwater and surface water shows that most of the water is within the range of the LMWL reference line. There are two points above the LMWL reference line with Ca-Cl water type. The result of this study indicated that the characteristics of water resources in the Jayapura area are influenced by the interaction between water and mineral weathering near the surface. This interaction provides a natural and good water resource potential in the region.

ABSTRAK

Hidrogeokimia dan isotop stabil $\delta^{18}O$ dan $\delta^{2}H$ merupakan metode kimia yang digunakan untuk memahami proses kimiawi aliran air di dalam akuifer. Penelitian ini bertujuan untuk mengidentifikasi karakteristik air tanah dan air permukaan di wilayah Jayapura. Sampel air diambil dari 87 titik pengamatan yang tersebar di seluruh area penelitian. Hasil analisis hidrogeokimia terhadap ion-ion utama yang disajikan dalam diagram Piper menunjukkan bahwa tipe air yang dominan adalah Ca/Mg-HCO_3. Selain itu, ditemukan pula tipe-tipe air lainnya seperti Ca-HCO_3^-, Na- HCO_3^-, Mg-SO_4^{2-} , Ca-Cl, dan Na-Cl. Air hujan digunakan sebagai garis referensi dalam diagram, yang dikenal sebagai LMWL (local meteoric water line), dengan persamaan H = 7,019$\delta^{18}O$ + 7,5162 dan koefisien determinasi sebesar 0,997. Analisis isotop stabil $\delta^{18}O$ dan $\delta^{2}H$ pada air tanah dan air permukaan menunjukkan bahwa sebagian besar sampel berada dalam kisaran garis referensi LMWL. Terdapat dua titik yang terletak di atas garis referensi LMWL dengan tipe air Ca-Cl. Temuan ini mengindikasikan bahwa karakteristik sumber daya air di wilayah Jayapura dipengaruhi oleh interaksi antara air dan proses pelapukan mineral di dekat permukaan. Interaksi tersebut berkontribusi terhadap potensi sumber daya air yang bersifat alami dan berkualitas di wilayah tersebut.

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1 Introduction

Jayapura is the capital of Papua Province, Indonesia. The study area includes Jayapura City and Jayapura Regency. Among the study areas there are Cyclops Mountains and Lake Sentani. This area has a very close relationship with the geological process and tectonic subduction mechanism that occurs between the Pacific Ocean plate and the Indo-Australian Continental plate (Husein et al., 2018; van Bemmelen, 1953).

The abundant water resources in the Cyclops mountain are used as a groundwater recharge area that is able to store rainwater and drain water to form watersheds. The water flows to the lowlands of Jayapura and Lake Sentani. Today, the Cyclops Mountains are one of the areas that supply fresh water to Jayapura and surrounding areas.

Each region has a different chemical composition of groundwater according to the displacement and ability to transport solutes (Clark, 2015). Water flows in contact with rocks and minerals that contain a variety of chemical compositions in the form of dissolved cations, dissolved anions and non-ion solutions (Toth, 1984). Hydrogeochemistry plays an essential role in studying the chemical composition and characteristics of water (Tikhomirov, 2016). Scope of hydrogeochemistry itself includes chemical processes that occur in water, chemical composition of water, chemical reactions between minerals and water. Geological processes have an important role in changing water quality including lithology, geological structure and mineral dissolution. Besides, human activities also greatly influence water quality such as the use of various chemicals that can affect the composition of natural water to become polluted.

The objective of this research is to perform a hydrogeochemical analysis, focusing on major ions, to identify the rock types that predominantly influence water quality (Hem, 1985; Gill, 2012). Additionally, stable isotope analysis of $\delta^{18}O$ and $\delta^{2}H$ is applied to determine the sources of water and the chemical processes occurring within the groundwater system (Clark, 2015). Together, hydrogeochemical and stable isotope analyses are used to characterize the potential properties of groundwater flow in the study area.

2 Regional Geology of the Study Area

The study area is located at 2000'N to 3000'N and 139030'East to 141000'East. The study area is 18,456.6 km^2, including the cyclops mountain range in the northern part of the study area. The regional study area includes geomorphology, stratigraphy, geological structure, hydrological conditions that refer to mapping publications (Suwarna,1995). The regional geology of the study area has been depicted on the Geological Map of the Cyclops Mountains (Figure 1). Geomorphology of the study area consists of alluvial plains (plateau) that occupy the vast Sentani plain with an altitude of 100-500 masl, structural hills with rivers flowing into the Tami plain with an altitude ranging from 100-700 masl and, Pre Tertiary Rock Mountains with an altitude of 2000-5000masl covering Jayapura City, Sentani and Depapre.

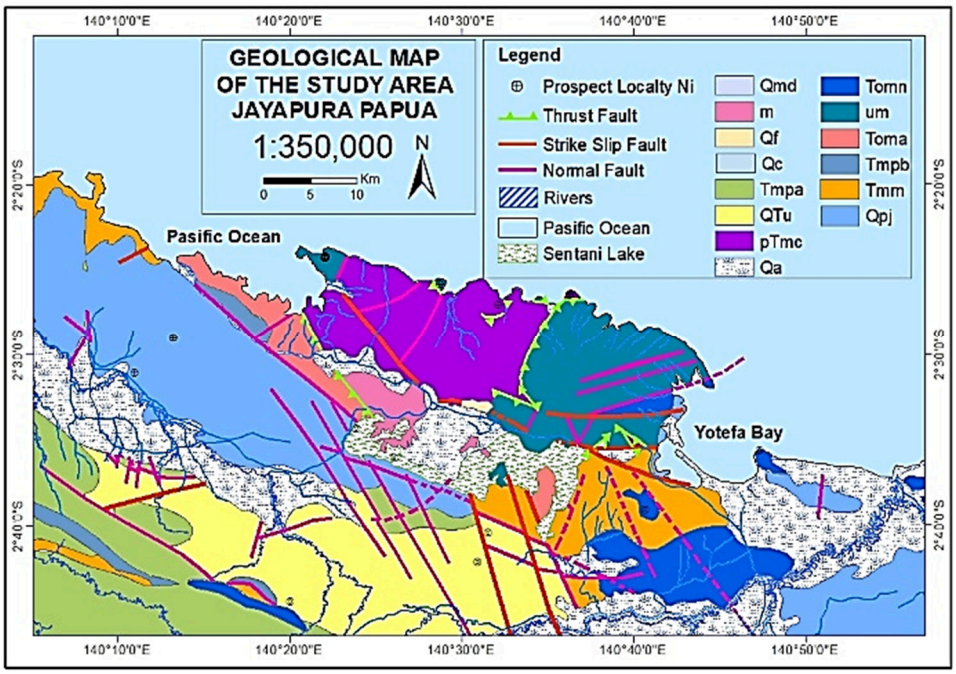


Figure 1 Geologic map (modified after Suwarna, 1995)

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3 Methods

3.1 Field Observation

The first step in this study is field observation for testing and taking water samples. Water samples are tested for TDS, Salinity and Electrical Conductivity using the Lutron WA-2017SD water quality test kit while pH testing uses Litmus Indicator Paper. Tests are carried out at 87 points which include 44 surface water, 43 groundwater and 4 rain water (Figure 2). The results of groundwater testing in the field show that TDS ranges from 23 mg/l-1550 mg/l. Electrical conductivity ranges from 30 µS - 2330 µS. pH ranges from 5-8. Salinity ranges from 0.00% - 0.13% (Table 1). Each water sample is put into an impermeable 50 ml high-density linear polyethylene (HDPE) plastic bottle.

The field test results indicate that all testing points in the field are in good condition and suitable for consumption. In the Depapre area, the pH is low at 5, and the Total Dissolved Solids (TDS) are below 1000 mg/l (Figure 3) due to it being the estuary where river water meets seawater.

However, in the groundwater with sample code S-14, based on the survey results of physical and chemical parameters in the field, the pH is 5, and the TDS is 1550, exceeding the water quality threshold (Government Regulation No. 22 of 2021). The electrical conductivity is 2330 µS, indicating poor quality (Wilcox, 1955), and the groundwater salinity in the area is 0.13% (≈1.3 PSU), classifying it as oligohaline (brackish) according to the Coastal and Marine Ecological Classification Standard. This indicates that agricultural activities may have contributed to water pollution (Sarkar et al., 2021).

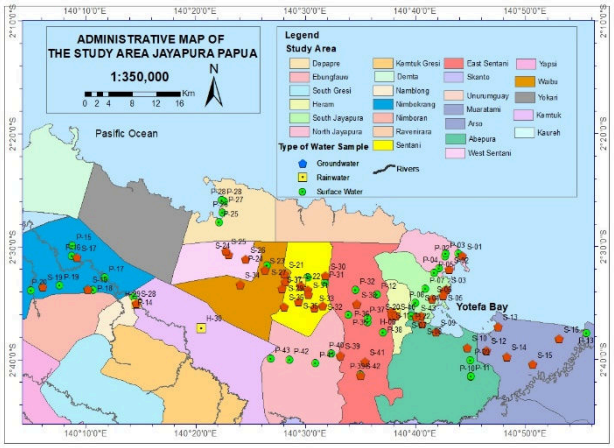


Figure 2 Administrative map of the study area and sampling locations

3.2 Laboratory Analysis

3.2.1 Hydrogeochemical Laboratory Analysis

The main element laboratory test analysis consisted of cations and anions using an Ion chromatography instrument (930 Compact IC Flex Metrohm, Herisau, Switzerland). The total number of samples analyzed is 44. The water chemistry analysis results were then verified with the calculation of ion balance (CBE) method set at 10% (Matthes, 1982) and (Hiscock, 2005). Calculation of ion balance is based on the classification of the main elements according to (Fetter, 2001), namely sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), sulphate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-), and carbonate (CO_3^{2}). The equation for CBE calculation is as follows:

Table 1 Testing and sampling points of water in Jayapura region

No	Sample	Field observation (max and min)					Sample Code	Number of Sample
		T (°C)	EC (µS)	Salinity	TDS (mg/l)	pH		
1	Groundwater	32	2330	0.13	1550	8	S01- S43	43
		26	102	0.01	82	5		
2	Big River	31	807	0.04	867	8	P04, P05, P08-P20,	22
		23	100	0.00	58	6	P23-P27, P32, P39	
3	Water Spring	31	750	0.04	504	8	P02, P03, P07, P21,	9
		25	130	0.01	83	6	P22, P31, P38, P42, P43	
4	Small River	29	590	0.03	399	7	P01, P33, P34, P41	4
		24	110	0.01	76	6		
5	Rain water	29	20	0.00	11	5	H06, H29, H30, H44	4
		25	0.00	0.00	2	5		
6	Sentani Lake	32	210	0.01	133	7	P35, P36, P37	3
		32	190	0.01	128	7		
7	Emfote Lake	31	30	0.00	23	6	P40	1
8	Estuary	25	110	0.01	71	5	P28	1
Number of Sample								87

$$CBE\ \% = \frac{\sum z \times mc - \sum z \times ma}{\sum z \times mc + \sum z \times ma}\ x\ 100 \qquad (1)$$

Where: CBE: ion equilibrium error (meq/l); z: charge of one ion; mc: molality of one cation; ma: molality of one anion

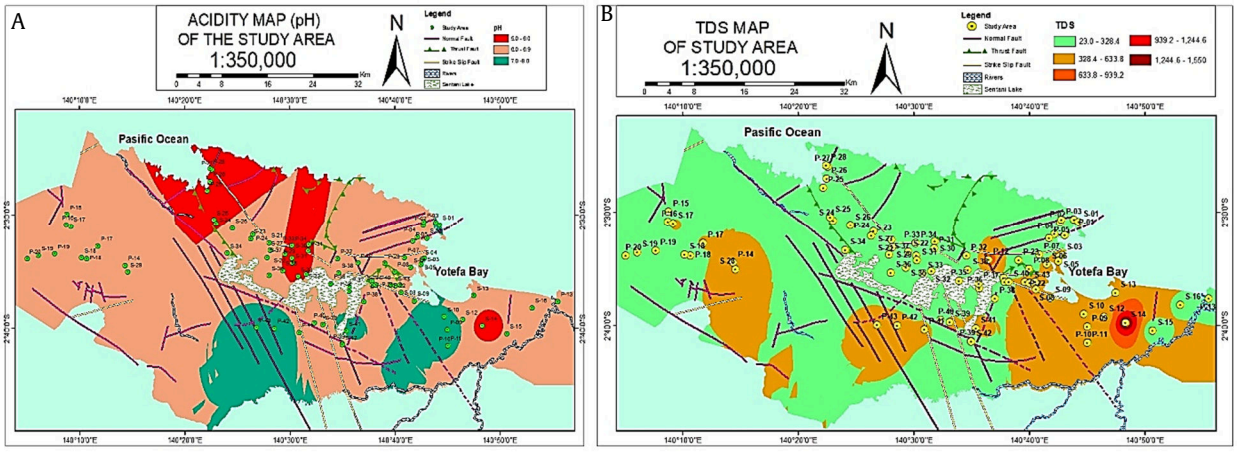


Figure 3 map of pH distribution (A) and TDS content (B) of water samples in the study area

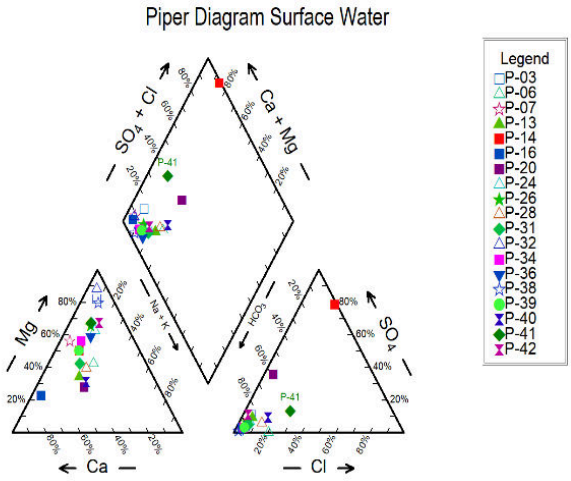


Figure 4 Surface water piper diagram

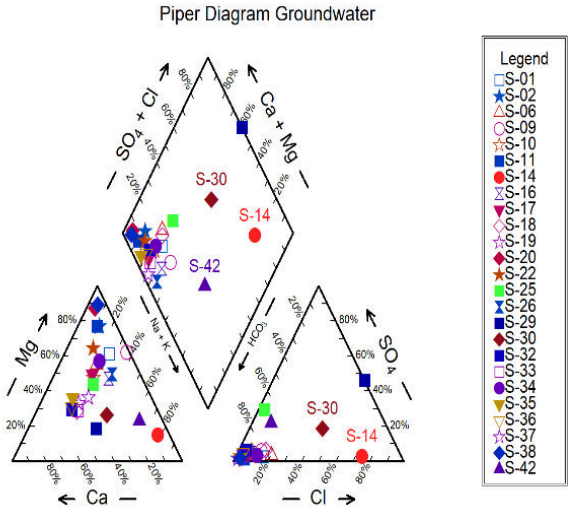


Figure 5 Piper diagram of groundwater

The results of ion equilibrium calculations were then plotted on Piper diagrams (Figure 4 and Figure 5). Piper diagrams are used to determine the evolution of water chemistry and water chemistry facies based on the classification of the dominant main ion zone (Fetter, 2001).

4 Result

4.1 Water Chemical Facies

The facies composition of water according to Clark (2015) on water samples in the study area are as follows:

4.1.1 Ca/Mg-HCO_3^- water chemical facies group

Ca/Mg-HCO_3^- is the most dominant water type in the study area. This can then be seen in the Mg-HCO_3 water type with a very large magnesium content of 28 sampling locations. While Ca- HCO_3^- is 11 sampling locations. Water type with constituent ions in the form of Mg^+ and Ca^+ as cations and HCO_3^- as an anion. Water with a dominance of Ca/Mg-HCO_3^- type magnesium bicarbonate groundwater shows that there is interaction between water and mineral weathering near the surface (Clark, 2015) so that the type of water is influenced by the chemical composition of rock lithology. This type of water is in the ultramafic (um) formation and the cyclops malachite group formation (pTmc) (Suwarna, 1995) which shows a dominant alignment from east to west (Figure 6).

4.1.2 Na/K-HCO_3^- water chemical facies group

The Na/K-HCO_3^- water type (softened bicarbonate water) was found at only one point in the center approaching the south of the study area, namely at the downstream of Lake Sentani in Yokiwa village. This type has sodium (Na^+) as cation and HCO_3^- as anion. Based on Matthes (1982) which provides an overview of the evolution process of the main element of the cation (Na^+). The presence of this type of water is in the downstream part of Lake Sentani so that it is a discharge area which results in the enrichment process of the element Sodium. This water type indicates that there has been a softening process to remove hardness minerals such as magnesium (Mg^+) and calcium (Ca^+). This process occurs due to softening or other processing that replaces alkaline earth ions with alkaline ions.

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4.1.3 Ca/Mg-SO_4^{2-}/Cl^- water chemical facies group

The Mg-SO_4^{2-} (magnesium sulfate) water type in the study area is divided into 2, namely Mg-SO_4^{2-} and Ca-Cl. This type of water is dominated by alkaline earth metals. The Mg-SO_4^{2-} water type in the research area is found in the Grime Hamonggrang Nimboran river flow in the western part of the research area. The Grime River is a recharge area, so it is rich in Mg and SO_4^{2-} (Chebotarev, 1995).

This type of water contains magnesium (Mg^+) as cation and SO_4^{2-} as anion. This type of water is found in lithologies composed of limestone so that when water passes through this layer, it can dissolve minerals including magnesium and sulphur which produces Mg SO_4^{2-} water. The lithological composition, as depicted on the geological map (Figure 6), comprises Alluvial formation, Coastal Deposits Qa, and Jayapura Formation (Qpj). SO_4^{2-} can come from the natural erosion process of rocks or can also come from pollutants. This type of water is in the river.

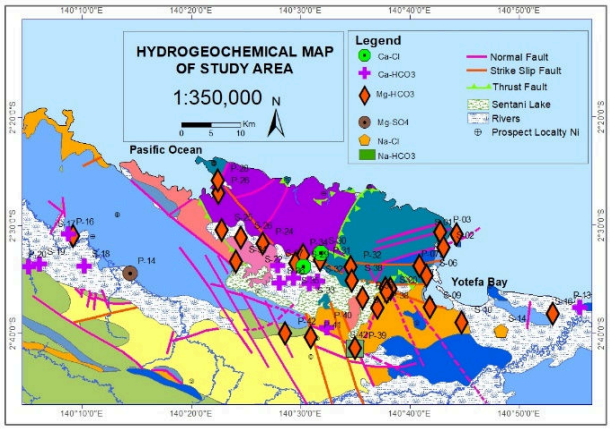


Figure 6 Hydrogeochemical facies map of study area

Calcium chloride (Ca-Cl) water type is characterized by calcium (Ca^{2+}) as the cation and chloride (Cl^-) as the anion. In the study area, two sampling sites exhibiting this water type have been identified—some located at the foothills of Mount Cyclops and others near Lake Sentani. This water is classified as hypersaline, indicating a salt concentration significantly higher than that of typical seawater. It contains elevated concentrations of calcium (Ca^{2+}), sodium (Na^+), and chloride (Cl^-) (Clark, 2015). These hypersaline waters are situated between the foothills of the Cyclops Mountain Range and Lake Sentani. The characteristics of this water type are considered significant and are likely attributable to ancient geological processes. Moreover, the substantial inflow from Lake Sentani contributes to the accumulation of calcium chloride in these waters.

4.1.4 Na/K-SO_4^{2-}/Cl water chemical facies group

Sodium chloride (Na-Cl) water type contains sodium (Ca^+) as cation and Cl^{2-} as anion. Na-Cl water type is only found at 1 point at the Tami location. This location is in the eastern part of the study area with relatively low morphological conditions and is near the coast. Water with high salinity and chloride derived from groundwater flow travel process water tends to change slowly the chemical composition of existing water from upstream Mg and Ca to downstream and Na which leads to the chemical composition of seawater (Chebotarev, 1995). Conditions indicate that this area is dominated by very high salinity levels.

4.2 Isotope Analysis ($\delta^{18}O$ and δ^2H)

Isotope analysis of $\delta^{18}O$ and δ^2H was carried out based on the fractionation of heavy and light isotopes. 87 water samples that have been prepared in a small bottle (vial) of 1.9 ml are then tested using the Picarro L2130- Isotope and Gas Concentration Analyzer instrument. The results of the stable isotope testing of Oxygen 18 and deuterium are made in the form of statistical parameters as shown in Table 2.

Table 2 Summary of stable isotope statistics in the study area

Statistic Parameters	Water sample type		
	Rain water	Surface water	Ground water
$\delta^{18}O$‰ Max	-4.88	-2.01	-2.21
$\delta^{18}O$‰ Min	-8.83	-8.74	-9.04
$\delta^{18}O$‰ Average	-6.85	-7.14	-7.34
$\delta^{18}O$‰ Standard Deviation	2.20	1.20	1.38
δ^2H‰ Min	-27.16	-23.25	-3.99
δ^2H‰ Max	-54.85	-53.98	-55.93
δ^2H‰ Average	-41.10	-44.36	-45.31
δ^2H‰ Standard Deviation	15.59	6.09	10.42

The calculation analysis of oxygen 18 and deuterium compared to the isotope ratio of Standard Mean Ocean Water (SMOW), can be calculated by the following equation:

$$\delta^2H_{sampel} = \left(\frac{(^2H/\,^1H)_{sampel}}{(^2H/\,^1H)_{VSMOW}} - 1\right) \text{x } 1000\,‰ \quad (2)$$

$$\delta^{18}O_{sampel} = \left(\frac{(^{18}O/^{16}O)_{sampel}}{(^{18}O/^{16}O)_{VSMOW}} - 1\right) \text{x } 1000\,‰ \quad (3)$$

The general equation that applies globally to changes in ^{18}O and ^2H content of rain (Craig, 1961) is: $\delta^2H = 8.13\ \delta^{18}O + 10.8$ ‰. This equation is known as the Global Meteoric Water Line (GMWL). The GMWL is an average of a number of local or regional MWLS, which differ from the global due to differences in climate and geographic parameters (Clark, 2015). The stable isotope composition is further plotted in Figure 7.

Rainwater Oxygen-18 values range from -8.83‰ to -4.88‰, while deuterium ranges from -54.85‰ to -27.16‰. The mean $\delta^{18}O$ and δ^2H values of rainwater were -6.85‰ and 41.10‰ respectively. The regression line of rainwater is $\delta^2H = 7.1019\ \delta^{18}O + 7.5162$ with

coefficient of determination r^2 = 0.997. Oxygen-18 values of surface water ranged from -8.74‰ to -2.01‰ while deuterium values ranged from -53.98‰ to -23.25‰. The mean δ18O and δ2H values of surface water were -7.14‰ and 44.36‰ respectively. The regression line of surface water was $\delta^2H = 4.7612\ \delta^{18}O$-10.373 with coefficient of determination r^2= 0.8747 (Figure 8).

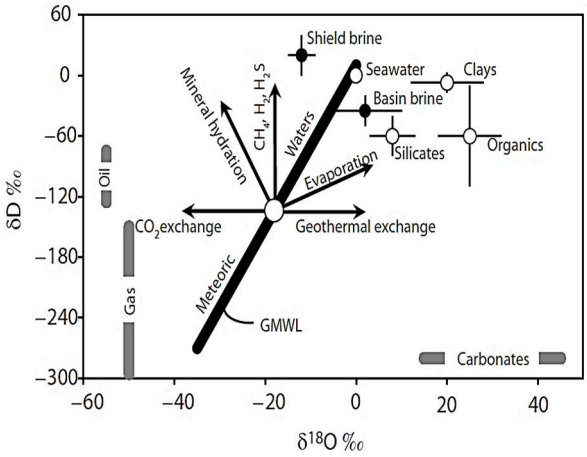


Figure 7 Range of $\delta^{18}O$ and δ^2H for various reservoirs and mechanism of isotopic composition change of meteoric water (Clark, 2015)

Groundwater (well) Oxygen-18 values ranged from -9.04‰ to -2.21‰ while deuterium values ranged from 55.93‰ to -3.99‰. The mean $\delta^{18}O$ and δ^2H values of surface water were -7.34‰ and 45.31‰ respectively. The regression line of groundwater (well) is $\delta^2H = 7.4357\ ^{18}O$+9.2994 with coefficient of determination r^2= 0.9746. Isotopic composition of rainwater, surface water and groundwater (wells) are plotted in Figure 9. Rainwater on the graph is referenced as the Global Meteoric Water Line (GMWL) with slope (7.10) and intercept (7.52) of rainwater, surface water slope (4.76) and intercept (-10.37) while in groundwater slope (7.44) and intercept (9.30). The slope value and intercept value determine the change in the line on the graph.

Rainwater is used as a reference in determining the size of the changes that occur in surface water and groundwater, so by observing Figure 9. it can be concluded that, there are changes that result in the intersection of groundwater and surface water. The line indicating groundwater has increased quite drastically because it has an intercept value of 9.30 and a slope value of 7.44. Meanwhile, if observed in surface water which has an intercept value of -10.37 and a slope value of 4.76. Thus, the slope value of surface water (-10.37) affects the line on the graph (has a minus value).

The results of stable isotope analysis of $\delta^{18}O$ and δ^2H are then depicted on a plot graph of the ratio of deuterium to oxygen in surface water and groundwater (Figure 8) with rainwater as the local meteoric water line. The graph shows that there is a variation in the ratio value on the local meteoric water line (LMWL), the surface water and groundwater samples are dominantly on the line. However, some samples are not exactly on the line (Figure 8).

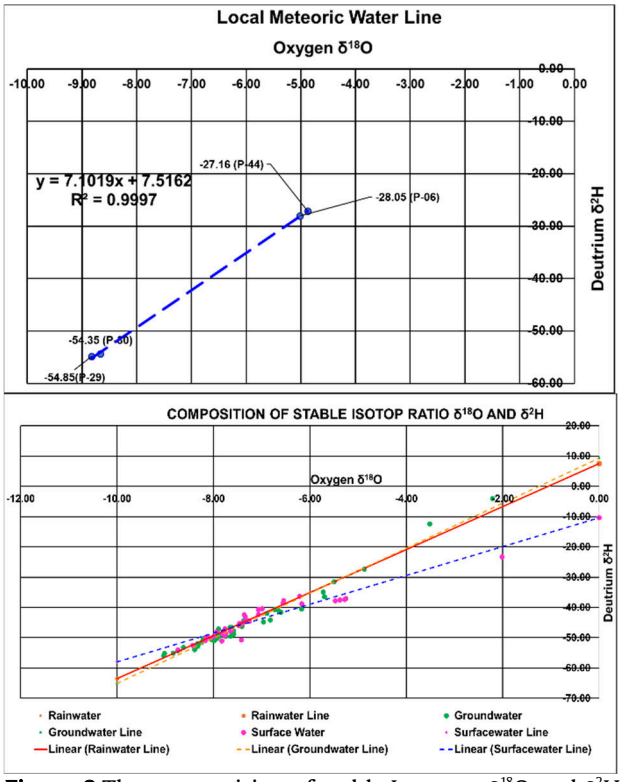


Figure 8 The composition of stable Isotopes $\delta^{18}O$ and δ^2H in rainwater, groundwater, and surface water

5 Discussion

5.1 Correlation of Major Ion Composition and Rock Source Origin

The chemical process of water as a solvent and rock mineral can make the chemical composition of water change from one place to another. To find out the source of the rock origin contained in the main ion composition of water, it is necessary to correlate the main ion composition in and the rock source. Zuurderg and Van der Weiden (1985, in Appelo and Postma, 1996), have made a correlation between the main ion composition in water and its possible rock source. The relationship between the piper diagram in the study area and the diagrams made by Zuurderg and Van der Weiden, as shown in Figure 9.

The correlation in the Figure 9c shows that in the research area the dominant rock is limestone marl and magmatic rock. The piper diagram plot results show that the Ca/Mg-HCO_3^- water type is very dominant in the research area. According to the plot results on the geological map of the cyclops mountains (Figure 6) this water facies forms a line from east to west in the

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ultramafic formation (um) and the cyclops malachite group formation (pTmc). The presence of magnesium (Mg+), an alkaline earth metal, is related to geological processes. Along these two lithologies there are straight faults (Figure 6). This shows that the chemical composition of water will experience a high increase in concentration when it is near or in contact with the fault zone. Where one of the functions of the fault is as a fluid path (Zhang, 2009). The rocks of the cyclops mountains undergo intense chemical weathering processes (Krause, 1965; Zglinicki and Szamałek, 2020). The magnesium content of Mg# in olivine minerals is close to olivine from mid-ocean ridge peridotites (Zglinicki and Szamałek, 2020; Monnier et al., 1999).

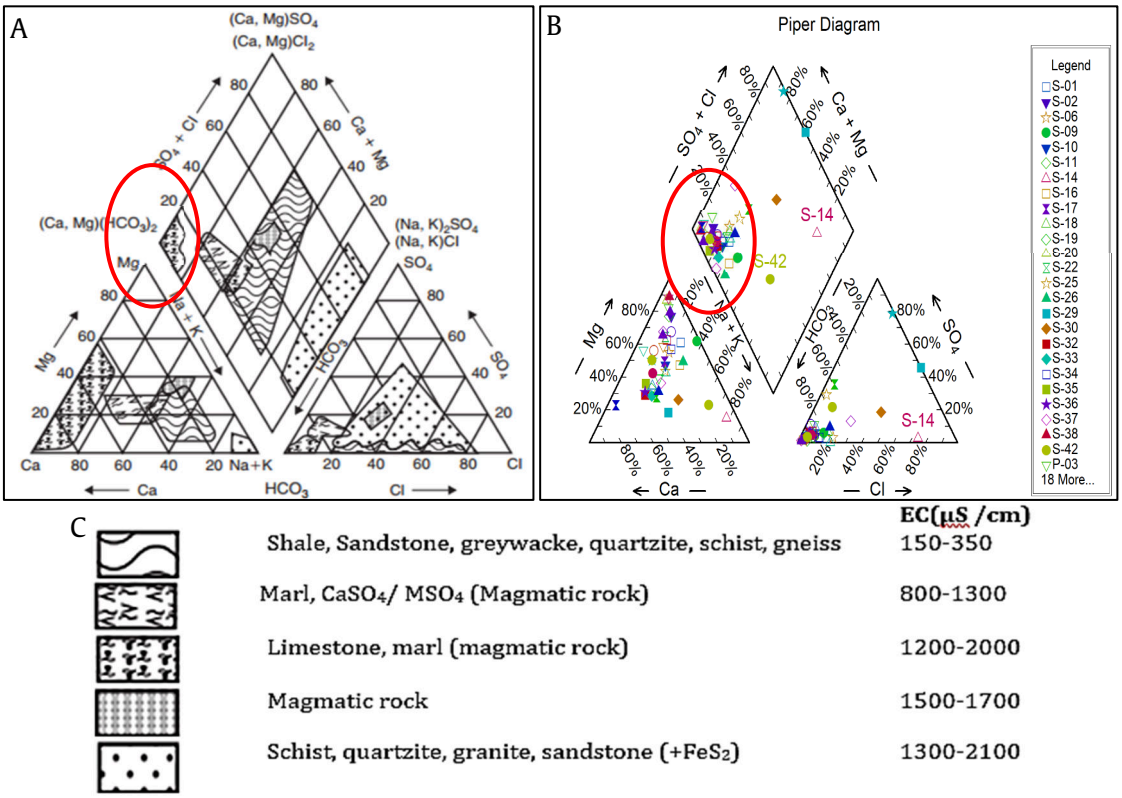


Figure 9 Piper plots of anions and cations sampled in the study area (A) Zuurdeeg and Van der Weiden, 1985 in Appelo and Postma, 1996; (B) Anion and cation plots sampled in the study area) and (C) is a descripstion of the originating rock source

Peridotite rocks originating from supra subduction zone environments formed due to tectonic processes derived from ultramafic rocks (Monnier et al., 1999, Bodinier and Godard, 2003). Olivine minerals are derived from dunites and harzburgites in the Cyclops Mountains (Monnier et al., 1999). Olivine is a very important mineral for analyzing the origin of rocks (Arai, S. 1980). The high magnesium (Mg^{+}) content derived from olivine minerals and the very low calcium (Ca) content have undergone metasomatic processes associated with Ca-boninite melt reactions (Zglinicki and Szamałek, 2020).

Groundwater and surface water in the study area interact directly with ultramafic minerals, primarily olivine and pyroxene, leading to the dissolution of significant amounts of Mg^{2+} and minor Ca^{2+} into the hydrogeochemical system. This water–rock interaction produces the dominant Mg–HCO_3 facies observed in the Piper diagram, indicating that the chemical composition of the groundwater is controlled by the weathering of supra-subduction zone peridotite. Consequently, the dominance of Mg in the water chemistry demonstrates that the originating rock source is not carbonate lithologies such as limestone or marl, but rather altered peridotite complexes rich in olivine and pyroxene.

5.2 Stable isotope ratio interpretation of $\delta^{18}O$ and $\delta^{2}H$

The results of stable isotope analysis of $\delta^{18}O$ and $\delta^{2}H$ are then depicted on a plot graph of the ratio of deuterium to oxygen in surface water (Figure 10) and groundwater (Figure 11) with rainwater as the Local Meteoric Water Line (LMWL). In surface water, several water samples were found to have stable isotope values of $\delta^{18}O$ and $\delta^{2}H$ away from the LMWL, this was influenced by the evaporation process that occurred from several surface water sources, including Lake Sentani, Emfrote Lake, rivers and streams and derived from sea water. In coastal areas (beaches) the stable

isotope values of oxygen 18 and deuterium are heavy and are away from the LMWL line because they are rich in chlorides and have higher temperatures. The values of oxygen 18 and deuterium in surface water range from -7.83‰ to -2.014‰ and -51.04‰ to -23. 25‰ (Figure 10).

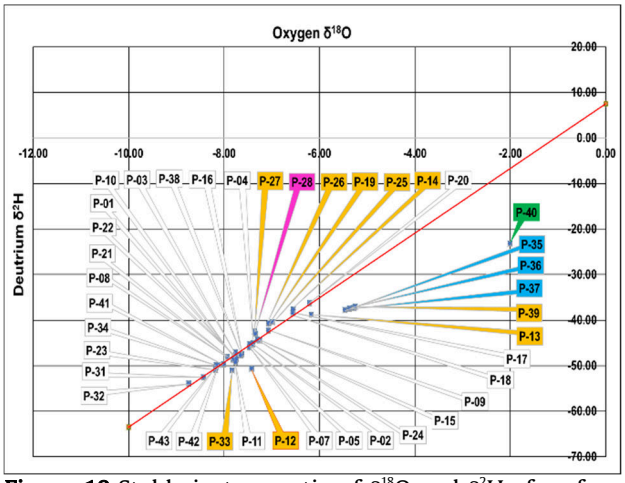


Figure 10 Stable isotope ratio of $\delta^{18}O$ and $\delta^{2}H$ of surface water

The ratio of stable isotopes $\delta^{18}O$ and $\delta^{2}H$ is heaviest in Emfote Lakes which is -2.014‰ and -23.25‰, consists of several color variations that show samples away from the Local Meteoric Water Line (red line) including yellow color shows the flow of rivers and streams, green color shows Emfote Lake, easy blue color shows Sentani Lake, purple color shows the estuary (meeting between river water and sea water) and white color shows samples along the LMWL.

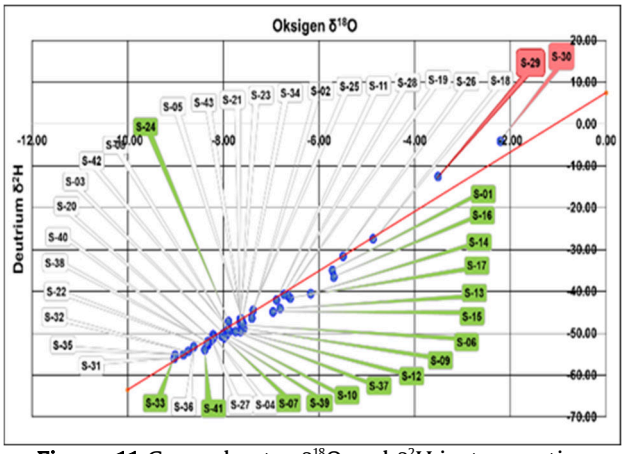


Figure 11 Groundwater $\delta^{18}O$ and $\delta^{2}H$ isotope ratios

The results of the analysis of stable isotope ratios $\delta^{18}O$ and $\delta^{2}H$ in groundwater showed that some water samples were not located exactly on the Local Meteoric Water Line (Figure 11). This can be indicated because at the sampling location there is interaction between water, rocks and geological processes (Figure 6). The geological processes in question are rising faults, falling faults, strike-slip faults and faults that are thought to be located at or near the research site. Groundwater samples S-29 and S-30, which are located between the foot of the cyclops mountain range and Sentani Lake, are far from the LMWL. The results of the $\delta^{18}O$ and $\delta^{2}H$ isotope ratio plots show that the area is above the LMWL line. This analysis indicates that the isotopic composition is influenced by geological processes that interact with water originating from the Earth's crust (Clark, 2015).

5.3 Hydrogeochemical and Stable Isotope Relationships

According to Clark (2015), the $\delta^{2}H$ and $\delta^{18}O$ isotope composition of groundwater changes due to geochemical reactions in the subsurface. The water samples away from the LMWL when correlated with the results of the main element analysis on the piper diagram (Figure 9) the plot results show that the dominant water samples are of the Mg/Ca-HCO_3^- type. This type of water comes from the dissolution of rocks in the ultramafic (um) lithology and the Cyclops Malachite Group (pTmc) lithology found in the cyclops mountains with the main mineral being olivine (Mg, Fe)$_2SiO_4$. Olivine is a group of minerals used to analyse mantle-origin rocks that are above the mafic and ultramafic magmas (Li et al., 2012). The results of the $\delta^{18}O$ and $\delta^{2}H$ stable isotope ratio plots show that most of them are at LMWL and are influenced by weathering of rocks near the surface in the same water type.

In surface water samples from the results of the $\delta^{18}O$ and $\delta^{2}H$ stable isotope ratio plots show that some water samples move away from the LMWL this is due to the influence of very high evaporation from Lake Sentani and Telaga Efrote. These samples have the same water type which is Mg-HCO_3^-.

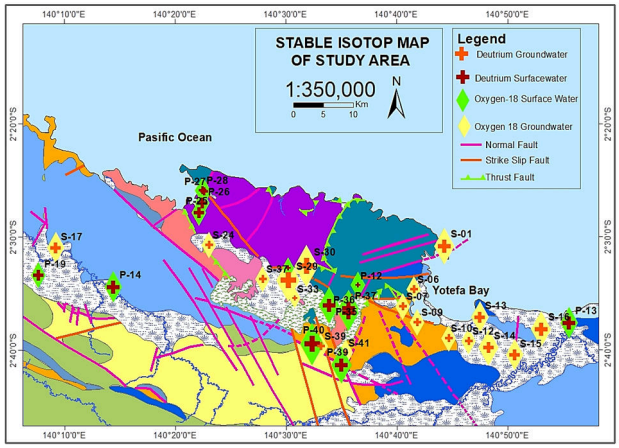


Figure 12 Stable isotop $\delta^{18}O$ and $\delta^{2}H$ map of study area

There are two water sample points S-29 and S-30 which are above the LMWL. The plot results on the paper diagrams show a Ca-Cl water type and pH of 6. The plot results on the Ion balance diagram (Figure 12)

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show very high concentrations of calcium and chloride. This water sample point was found between the slopes of the Cyclops Mountains and Lake Sentani. This is well water taken at a depth of 10 meters and 12 meters. According to Clack 2015, water that is above the LMWL and has a Ca-Na-Cl water type is a group of water types originating from shield brine (hypersaline water). This is very much related to the history of geological processes on the Earth's crust.

The Cyclops Mountains are a large fragment of oceanic crust, where there are ophiolites including residual mantle peridotites (harzburgite and dunite), cumulate gabbro, dolerite, basalt, and small amounts of boninitic lavas (Monnier et al., 1999). Tectonic processes during the Pleistocene, the marine arm south of the Cyclops Mountains was cut off from the Pacific Ocean and turned into a freshwater lake which is now Lake Sentani (van Bemmelen, 1953). There are traces of marine life that are now extinct (Hem, 1985). Sediment samples of arcelacean microfauna are sparse, which is often associated with brackish water conditions, raising the possibility of residual salinity (from trapped seawater) in deep parts of the lake. Current geochemical and stable isotope evidence supports the origin of the study, an unusual deuterium enrichment resulting from plots above the LMWL (Bottomley et al., 1994; Greene et al., 2008). Rocks that are in the active continental crust area because they are on the edge of the continental crust, around the subduction zone will experience a continuous rock cycle due to the uplift process (Hakim, 2019).

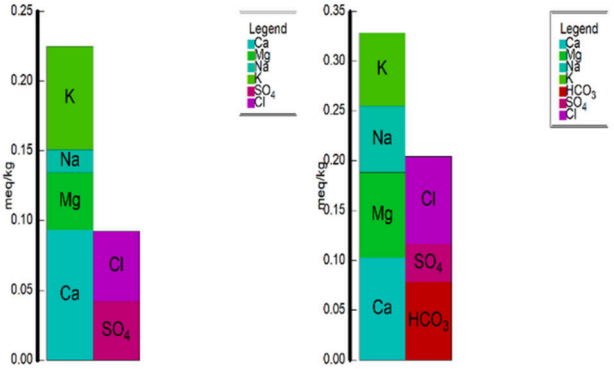


Figure 13 Ion balance diagram of sample S-29 and S-30

From the plot results on the geological map in Figure 12, this water type is in the alluvium fan lithology which is composed of a collection of ultramafic and cyclops malachite. In the cyclops malachite there are schists rich in chlorite minerals associated with other minerals. Combining historical geological evidence with hydrogeochemical data, including the ion balance results presented in Figure 13, it can be inferred that the dominant ions are calcium (Ca^{2+}) and chloride (Cl^{-}). From the various discoveries of historical geological evidence that have existed before, it can be drawn a common thread that the Ca-Cl water type above LMWL is water that comes from the raising of the ocean floor called the Brien Shield.

5.4 Hydrogeochemical Facies Evolution

Analysis of the hydrogeochemical facies evolution of water was conducted by analyzing the major constituents using a hydrogeochemical facies diagram (HFE Diagram). Cross-plots between these eight major constituents will give an idea of the quality of water that has not been intruded and that has been intruded (Giménez-Forcada, 2010). The plots show that the Kimiri Sentani area (S29) and BTN area (S30) are intruded in the Ca-Cl Puskopad water-type facies and Koya Barat in the NaCl water-type facies.

The results shown in Figure 14 are consistent with the evolution of groundwater hydrogeochemical facies in the study area. Sampling points S29 and S30 exhibit a Ca–Cl water type, which corresponds to an average pH value of 6, as indicated on the interpolation map (Figure 3). The presence of calcium chloride (CaCl) water type around the pTmc and um formations indicates that there is interaction between rock formations, geological structures (faults), and fluid flow. Based on field parameter data and hydrogeochemical analysis, the water quality is still within acceptable limits according to Government Regulation No. 22 of 2021.

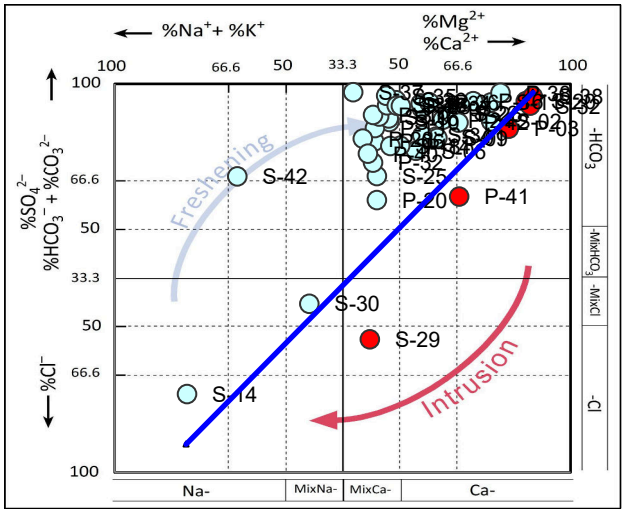


Figure 14 Evolution of groundwater hydrogeochemical facies (Giménez-Forcada. 2010)

In contrast, groundwater sampled from location S14 is characterized by a Na–Cl water type, indicative of seawater intrusion, as supported by field physical chemical that exceed water quality thresholds. Isotopic analysis indicates that these samples lie below the Local Meteoric Water Line (LMWL), suggesting that the water has experienced seawater evaporation processes. As shown in Figure 15, these

samples exhibit high Na-Cl concentrations and are collected from sampling location near the coastal region of Tami. Field testing further indicates that the groundwater in Tami has been impacted by agricultural activities, as evidenced by the significantly elevated Na-Cl values observed in the major ion analysis, as illustrated in the ion balance diagram.

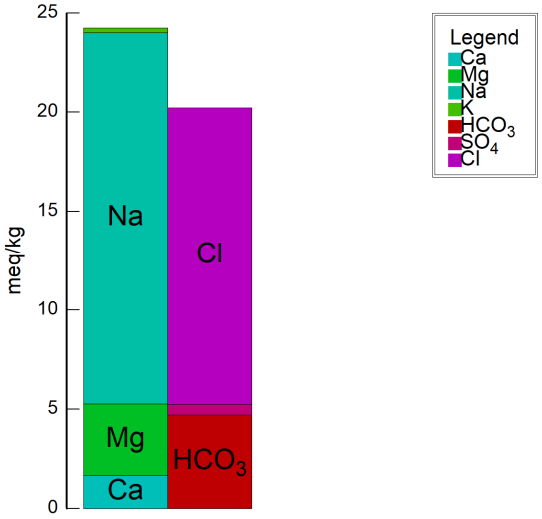


Figure 15 Ion balance diagram of Sample S-14

6 Conclusion

The results of this study can be concluded several things including:

1. Potential water characteristics in the Jayapura area are dominantly derived from underground water with a very high magnesium (Mg^{+}) and rainwater (HCO_3^{-}) which produces Mg-HCO_3^{-} water type. This type of water comes from the interaction between water and mineral weathering near the surface so that the characteristics of this water are influenced by the chemical composition of rock lithology. The results of the $\delta^{18}O$ and $\delta^{2}H$ isotope ratio plots show that most of them are at the LMWL and are influenced by rock weathering near the surface of the same water type. It can be concluded that water in the Jayapura area generally has natural water potential characteristics and is suitable for consumption.
2. From the results of the Mg-HCO_3^{-} water type plot on the geological map, it illustrates that there is a straight line from East to West following the straight shear fault, this explains that there is a high increase in concentration when the water is near or in contact with the straight shear fault zone so that there is interaction between water and mineral weathering near the surface.
3. In surface water samples from the results of the $\delta^{18}O$ and $\delta^{2}H$ stable isotope ratio plots show that some water samples move away from the LMWL this is due to the influence of very high evaporation from Lake Sentani and Telaga Efrote. These samples have the same water type which is Mg-HCO_3^{-}.
4. The results of the isotope plot show that there are two points above the LMWL with Ca-Cl water type which can give an idea that this water comes from the process of raising the ocean floor so that it includes the shield brine water type.
5. In the Tami area NaCl water type there is a sample of well water S-14 with the results of physical chemical parameters in the field pH 5 and TDS 1550 mg/l has exceeded the water quality threshold, Electrical condutivity 2330 µS including poor quality and salinity 0.13% including brackish quality. This shows that the water in this area has been polluted due to agricultural activities.

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