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RESEARCH ARTICLE

Hydrogeochemical Characterization and Quality Assessment of Groundwater in Rumbai District, Pekanbaru: Implications for Sustainable Water Management

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Abstract

Groundwater is a vital source of clean water, valued for its high quality, abundant reserves, accessibility, and cost-effectiveness. As a result, effective management is crucial to ensure compliance with relevant standards. However, rapid population growth and increasing human activities have raised the demand for groundwater, which, in turn, impacts its characteristics. These changes can include altered composition, imbalances in autotrophic nutrients, contamination by heavy metals, and seawater intrusion. The availability of reliable groundwater quality data is essential for sustainable development in Pekanbaru City. This research aims to assess the groundwater quality in Rumbai District, explore its hydrogeochemical characteristics, and analyze the distribution of bicarbonate based on physical and chemical parameters. This study is particularly significant as there has been no previous hydrogeochemical analysis of the peatland areas in this region.

The research method involves a comprehensive analysis of groundwater conditions, focusing on both physical and chemical factors. The physical condition analysis includes the organoleptic assessment of smell to detect unusual odors, color inspection, and temperature. Total Dissolved Solids (TDS) and electrical conductivity (EC) levels are also measured, providing insight into the water's biological and chemical characteristics. The chemical condition analysis includes pH testing to assess the water's acidity or alkalinity, along with major ion analysis to evaluate the concentrations of cations like calcium, magnesium, sodium, and potassium, and anions such as chloride, sulfate, bicarbonate, and nitrate. For accurate results, proper sample collection using sterilized containers is critical, along with the use of replicates and instrument calibration. Data interpretation involves comparing the findings to established water quality standards, such as those from the World Health Organization (WHO), to assess the groundwater's suitability for consumption or other uses.

Based on chemical properties standardized by the Ministry of Health, such as the pH value of water still meets the standard of 7.7, Na+ with an average of all stations is 20.49 Mg/l which still meets the standard, HCO3- with an average of all stations is 59.63 Mg/l l still meets the standard, CI- with the average of all stations is 19.75 Mg/l still meets the standard, SO42- with the average of all stations is 2.81 Mg/l still meets the standard. At ST-01, ST-02, ST-03, ST-04, ST-05, and ST-09, the groundwater meets the standards based on chemical analysis but does not meet the standards based on physical analysis. Meanwhile, ST-06, ST-07, ST-08, and ST-09 meet the required water quality standards based on both physical and chemical standards. Therefore, at ST-01, ST-02, ST-03, ST-04, ST-05, and ST-09, the groundwater is not suitable for use. So based on its chemical properties it still meets quality standards but this groundwater is influenced by the physical properties of groundwater which is not suitable for use at several stations. This study identifies four types of groundwater characteristics: the Na(K)-SO4 type, found at stations ST-01, ST-02, ST-04, ST-07, and ST-04; the Na(K)-HCO3 type, found at station ST-03; the Ca(Mg)-HCO3 type, found at stations ST-05, ST-06, and ST-08; and the Ca(Mg)-SO4 type, found at station ST-10.

Keywords: *: Groundwater, physical properties, chemical properties, groundwater quality*

1. Introduction

Freshwater availability is a critical issue worldwide, with groundwater serving as a primary resource for drinking water and other essential needs, particularly in Indonesia. Groundwater offers several advantages over surface water, including natural filtration, reduced susceptibility to contamination, and availability during dry seasons (Carrard et al., 2019). However, rapid population growth and increasing human activities have led to a significant rise in groundwater utilization, placing pressure on its sustainability (Asadollahi et al., 2024; Zhang et al., 2020). These Athropogenic influences can alter groundwater characteristics, affecting both its quality and availability

Indonesia's geological diversity is shaped by various factors, one of which is the subduction zone between oceanic and continental plates that extends along the western coast of Sumatra, southern Java, and further eastward and northeastward across the archipelago (Hutchings & Mooney, 2021). A notable geological setting influenced by this tectonic activity is the Central Sumatra Basin, located in Riau Province. This region comprises rock formations ranging from the Carboniferous to the Quaternary period (Clarke et al., 1982). Such geological diversity plays a crucial role in determining the quantity and quality of groundwater resources.

Areas with peatland landscapes exhibit different water characteristics, often displaying darker coloration and more acidic pH levels (Lubis et al., 2016). Water quality assessments from periodic sampling at Bandar Kayangan Lake in Pekanbaru further confirm these trends, with pH values remaining relatively acidic and dissolved oxygen (DO) levels ranging from 2.4 to 6.5 mg/L, despite the lake not being classified as a peatland water body (Oktaviandora et al., 2014). Comprehensive evaluations using the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) indicate that water quality in Pekanbaru varies from poor to moderate (Yuliati et al., 2024).

Hydrogeochemical analyses conducted in Bukit Raya and Tenayan Raya, Pekanbaru, have identified four dominant groundwater facies: Na, Ca, Cl, and HCO_3. These groundwater facies result from dissolution processes and interactions between surface and subsurface water systems, particularly through rainwater infiltration and surface water intrusion (Rafi et al., 2020). The interconnection between surface water and groundwater is an integral part of the hydrological cycle, wherein changes in surface water conditions can directly influence groundwater quantity and quality.

Elevated levels of total coliform and biological oxygen demand (BOD) ranging from 8.78 to 17.5 mg/L further confirm the influence of human activities on surface water quality (Yuliati et al., 2023). Given the relatively high permeability of the geological formations in the study area, there is a potential for surface water infiltration to introduce contaminants into the groundwater system. Despite the increasing concern over water pollution, the extent of groundwater contamination influenced by the Siak River remains largely unexplored.
Hydrogeochemical methods are widely recognized as effective tools for understanding groundwater chemistry and its controlling processes (Kumar et al., 2009). By applying these approaches, this research seeks to establish a clearer correlation between Siak River water quality and the groundwater system in Pekanbaru, contributing to a deeper understanding of the hydrogeological processes influencing water resources in the region. Specifically, the study focuses on Sri Meranti Village, Rumbai Subdistrict, Pekanbaru City, Riau Province.

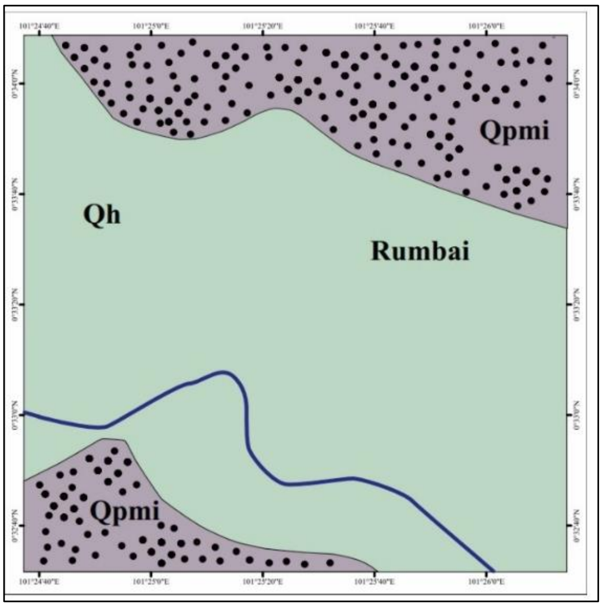

Fig 1. Regional Geological Map of the Study Area (M.C.G. Clarke & W. Kartawa, et al., 1982)

2. Geology Regional

Based on the regional geological map of the Pekanbaru sheet, the study area is located in the Central Sumatra Basin, which is a back arc area consisting of three formations: the Minas Formation (Qpmi), old surface deposits (Qp), and young alluvial surface deposits (Qh). The regional geology of the study area can be seen in (Fig 1.).

The stratigraphy of the study area consists of two formations as follows:

1. **Young Alluvial Surface Deposits (Qh)** These young alluvial surface deposits consist of clay, silt, smooth gravel, plant remains, and peat swamp residues. These deposits are exposed in the floodplain valley areas.
2. **Minas Formation (Qpmi)** The Minas Formation is a Quaternary deposit that is unconformably deposited above the Petani Formation. This formation consists of gravel, pebbles, sand, and clay.

3. Material and methods

In this research, 10 wells were measured to obtain water samples and groundwater levels in the research area. (Fig.2) The parameters used for analysis include physical properties in the form of color, odor, taste, temperature, TDS, EC, as well as chemical properties in the form of pH and major ions in the form of (Ca, Mg, Na, K, Cl, HCO3, and SO4). From the physical data and chemical properties data, the feasibility test for groundwater quality refers to the regulations of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010 and Number 32 of 2017 which regulate water quality standards (Menteri Kesehatan Republik Indonesia, 2017) (Table 1).

Table 1. Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010 and Number 32 of 2017 which regulate water quality standards

Type of Parameters	Parameters	Unit	Maximum Allowed Concentration
Physical Parameters	Odor	Sense of Smell	13 NTU scale
	Color	Sense of Sight	Color Less
	Taste	Sense of Taste	Taste less
	Total Dissolved Solids (TDS)		500 mg l-1
	Electrical Conductivity (EC)	YSI-Pro Measuring Instrument	Not Required
	Temperature		Air Temperature ±30°C
Chemical Parameters	pH	YSI-Pro Measuring Instrument	6.5 - 8.5 pH
	Ca2+	Laboratory Analysis	Not Required
	Mg2+		Not Required
	K+		Not Required
	Na+		200 mg l-1
	HCO3-		500 mg l-1
	Cl-		250 mg l-1
	SO4 2-		250 mg l-1

Groundwater chemistry data in the form of major ions is analyzed and converted into PPM units so that water characteristics can be analyzed using a piper diagram on the content of groundwater chemical elements in the form of major ions. The piper diagram is easier to use to determine facies characteristics in groundwater. (Fig.4) The dominant cations include Ca, Mg, K, and Na, while the most found anions are HCO3, SO4, and Cl. The hydrochemical characteristics of groundwater reflect the length of residence time or movement distance of groundwater in the aquifer (Adriansyah, 2021).

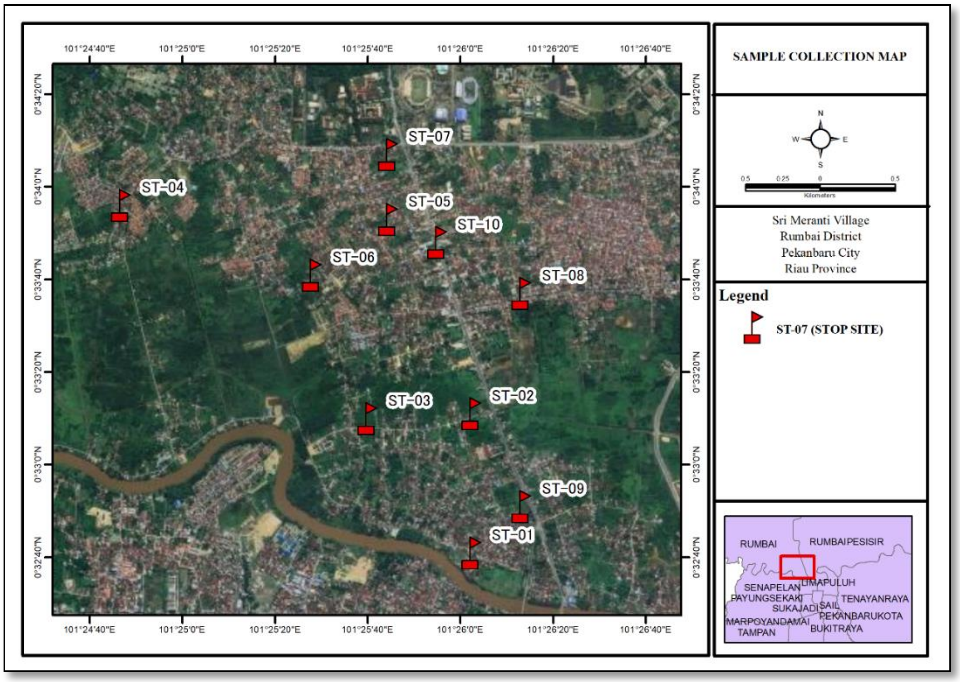

Fig 2. Sampel Collection Map

3. Results

3.1 Groundwater Flow Direction

Based on the data collection results, the initial data processing was carried out to determine the groundwater flow direction (MAT) in the study area, based on groundwater level data. Station 8 with the code (ST-08) has the highest groundwater level value of 11.93 m, while the lowest groundwater level is found at station 4 (ST-04) with a MAT value of 3.87 m. From all the groundwater level values, the direction of groundwater flow was found to be from east to west, except for the northeastern part, which flows towards the center (Figure 4.3).

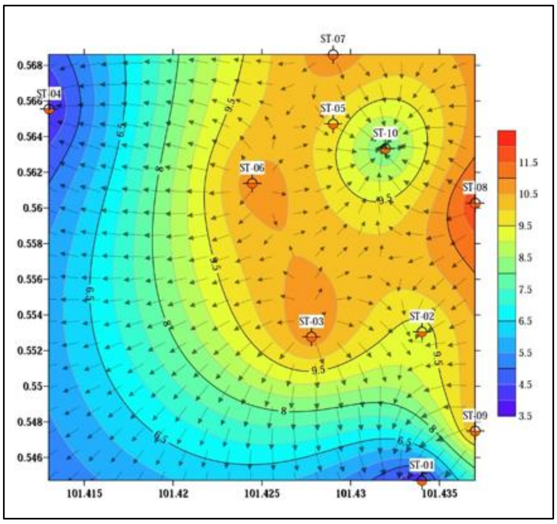

Fig 5. Groundwater Flow Map

3.2 Analysis physical Groundwater

From the results of the analysis of the physical properties of groundwater which was carried out on the 10 wells that were analyzed, it was obtained that the odor parameters had 3 colors, namely clear, brownish yellow and brown. From the taste parameter, there are two results, namely taste and tastelessness. The smell parameter has two results, smell and smell and no smell. From a temperature of 29.75 – 34.7 with an average of 30,650C. From TDS 281.4 mg/l – 40 mg/l with an average of 144.66 mg/l. from EC 7.28 µs/cm – 363 µs/cm with an average of 164.74 µs/cm.

According to the Regulation of the Minister of Health of the Republic of Indonesia No. 492/Menkes/Per/IV/2010 concerning the quality of drinking water in this area, there are several areas that are not suitable for use, such as at stations (ST-01, ST-02, ST-03, ST-04, ST-05, ST-09) declared not to meet consumption suitability standards. Therefore, water quality in the research area was further analyzed by referring to the 2017 Minister of Health Regulation which regulates water quality standards for sanitation purposes. Based on Minister of Health Regulation no. 32 of 2017 concerning environmental health quality standards for sanitation hygiene or clean water needs, groundwater suitable for these purposes must meet a number of requirements. These requirements include the absence of taste and odor, the temperature is within the range of ±30°C, and the total dissolved substances (TDS) do not exceed 1000 mg/l (Tabel 1 & Fig 6).

From the results of this analysis, it was found that several areas are suitable for use based on the regulations of the Minister of Health of the Republic of Indonesia, standard standards for ground water levels regarding the quality of drinking water and sanitation. There are several areas that are not suitable for use. Non-portable water, such as at stations (ST-01, ST- 02, ST-03, ST-04, ST-05, ST-09) are declared not to meet consumption suitability standards. Therefore, water quality in the research area was further analyzed by referring to the 2017 Minister of Health Regulation which regulates water quality standards for sanitation purposes.

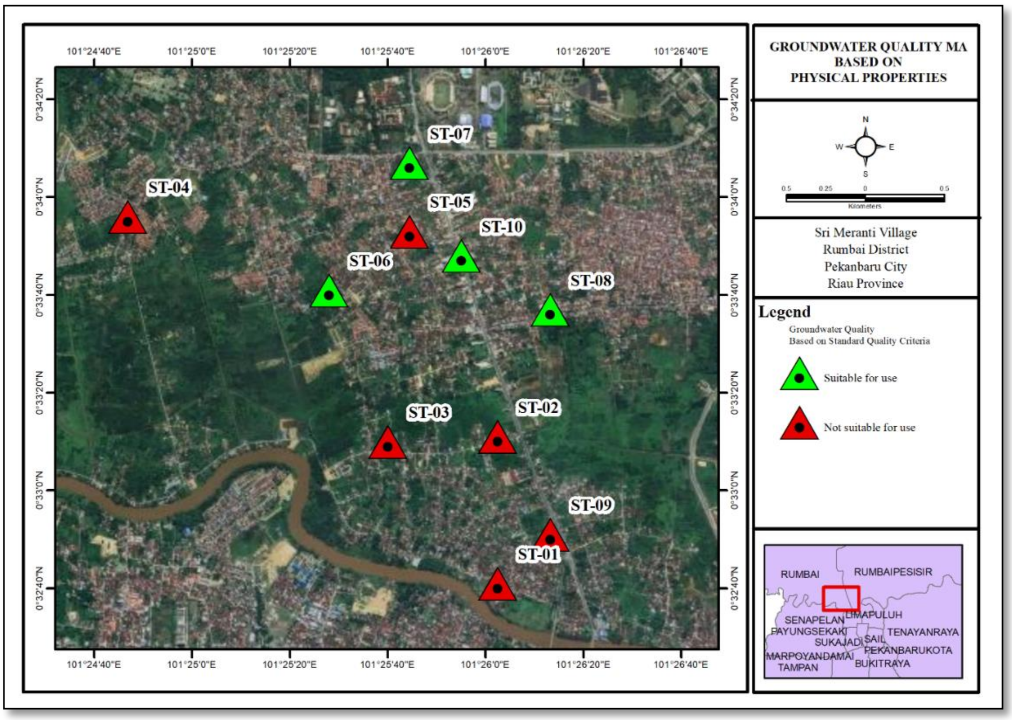

Fig 6. Groundwater Quality Map Based on Physical Properties According to the Ministry of Health's Water Quality Standards

Table 1. Results of Physical Parameter Analysis of the Research Area

Location Code	GWT (m)	Color	Taste	Odor	T $_{water}$ (^{0}c)	TDS (mg/l)	EC (µs/cm)	Quality Standards
ST-01	3.95	Yellowish Brown	tastes	odor	32	43	363	Non-Suitable for use
ST-02	9.2	Yellowish Brown	tastes	odor	29.99	40	80	Non-Suitable for use
ST-03	10.9	Brown	tastes	odor	34.7	201.1	89	Non-Suitable for use
ST-04	3.87	Yellowish Brown	tastes	odor	29.75	149	298	Non-Suitable for use
ST-05	9.87	Brown	tasteless	odor	30.1	49.94	7.28	Non-Suitable for use
ST-06	10.85	Clear	tasteless	odorless	30.06	102	203	Suitable for use
ST-07	10.9	Clear	tasteless	odorless	29.9	82	164	Suitable for use
ST-08	11.93	Clear	tasteless	odorless	29.85	136	271	Suitable for use
ST-09	10.6	Clear	tasteless	odorless	29.86	62	123	Non-Suitable for use
ST-10	7.85	Clear	tasteless	odorless	30.3	281.4	49.16	Suitable for use

3.3 Analysis Chemical Groundwater

From the results of the analysis of the physical properties of groundwater which was carried out on the 10 wells that were analyzed, the pH of the water and the chemical values of the major ions Ca, Mg, K, Na, HCO3, SO4, and Cl were obtained. With a pH value of 6.7 – 7.94 with an average of 6.69. Ca value 2.98 mg/l – 53.71 mg/l with an average of 15.64 mg/l. Mg with a value of 0.13 mg/l – 4.30 mg/l with an average of 1.99 mg/l. The Na value is 7.88 mg/l – 40.35 mg/l with an average of 20.46 mg/l. The K value is 3.03 mg/l – 9.5 mg/l with an average of 4.49 mg/l. HCO3 value with a value of 18.3 mg/l – 152.99 mg/l with an average of 59.63 mg/l. The SO4 value is 0.56 mg/l – 7.45 mg/l with an average of 2.81 mg/l. The CI value is 4.48 mg/l – 40.09 mg.l with an average value of 18.79 mg/l (Tabel 2 & Fig 7).

Based on Minister of Health Regulation no. 32 of 2017 concerning environmental health quality standards for sanitation hygiene or clean water needs, groundwater suitable for these purposes must meet a number of requirements. These requirements include an acidity level (pH) between 6.5 - 8.5, Na with the requirements of 200 mg/l, HCO3 500 mg/l, CI 250 mg/l, SO4 250 mg/l, from the quality standard chemical requirements the value is still according to the standards required by the Minister of Health's regulation.

Table 2. Results of Chemical Parameter Analysis of the Research Area

Location Code	Major Ion Concentration (Mg/l)								
	pH	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	$HCO3^{-}$	CI^{-}	$SiO4^{-2}$	Quality Standards
ST-01	7,73	21,97	0,96	9,5	40,35	118,83	40,09	3,22	Meet the standard
ST-02	7,92	4,33	0,13	3,71	12,27	25,62	9,46	0,56	Meet the standard
ST-03	7,71	3,77	0,62	3,03	14,12	42,58	4,48	1,55	Meet the standard
ST-04	7,94	13,48	0,85	3,86	38,15	18,3	37,34	7,45	Meet the standard
ST-05	6,7	4,59	2,61	3,43	7,88	43,43	7,04	4,42	Meet the standard
ST-06	7,91	11,87	3,55	4,91	25,14	88,45	13,43	1,73	Meet the standard
ST-07	7,91	2,98	1,56	3,22	24,59	32,94	21,07	4,63	Meet the standard
ST-08	7,93	53,71	3,58	4,15	10,49	152,99	14,19	3,01	Meet the standard
ST-09	7,94	14,35	1,71	3,36	21,2	30,5	22,07	0,68	Meet the standard
ST-10	7,28	25,31	4,3	5,71	10,39	42,7	28,35	0,89	Meet the standard

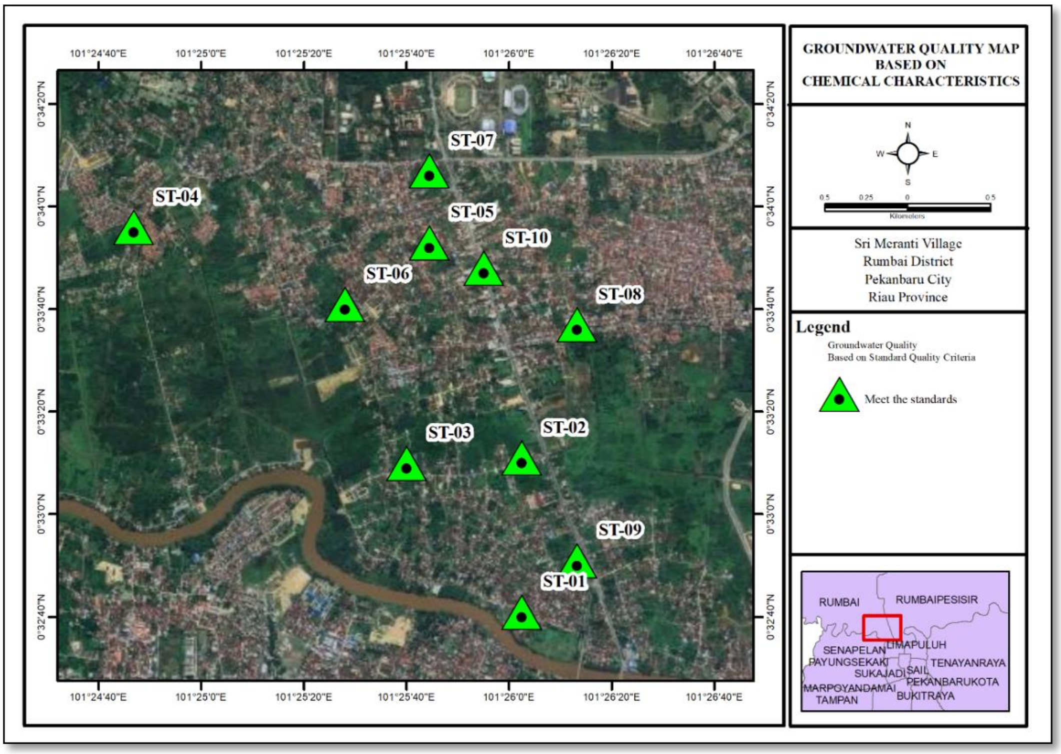

Fig 7. Groundwater Quality Map Based on Chemical Properties According to the Ministry of Health's Water Quality Standards

3.3 Analysis Diagram Piper

Hydrochemical facies concept was developed as an approach to understand and classify water composition into various specific categories . According to (Cherry & frezzy 1979) ion concentrations change along the groundwater circulation pathway, which in turn affects the solubility zones that determine the distribution of cations and anions. (Domenico and Scbwartz, 1990) stated that in a large groundwater flow system, the dominant anion facies gradually shifts from HCO_3 in the upper region, to SO_4 in the middle area, and finally to Cl in the lower region.

Table 3. Result of Piper diagram analysis

Group	Location Code	Piper Diagram	CI Ion Ratio
1	ST-01	Na(K)-CI(SO_4)	Water-Rock Interaction / Anthropogenic Activities
1	ST-02	Na(K)-CI(SO_4)	Water-Rock Interaction / Anthropogenic Activities
1	ST-04	Na(K)-CI(SO_4)	Water-Rock Interaction / Anthropogenic Activities
1	ST-07	Na(K)-CI(SO_4)	Water-Rock Interaction / Anthropogenic Activities
1	ST-09	Na(K)-CI(SO_4)	Water-Rock Interaction / Anthropogenic Activities
2	ST-03	Na(K)-HCO^3	Water-Rock Interaction / Anthropogenic Activities
3	ST-08	Ca(Mg)-HCO^3	-
3	ST-05	Ca(Mg)-HCO^3	-
3	ST-06	Ca(Mg)-HCO^3	-
4	ST-10	Ca(Mg)-Ci(SO_4)	-

*Chemical data present in Meq/l

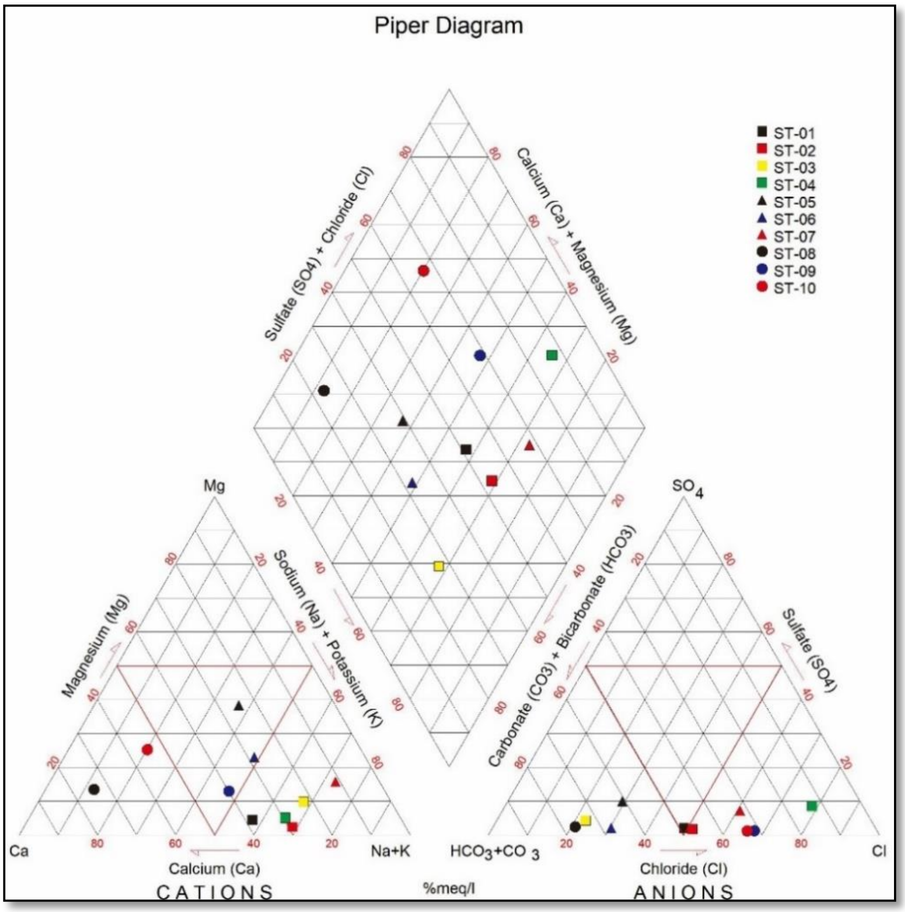

Fig 8. Result of Piper diagram analysis

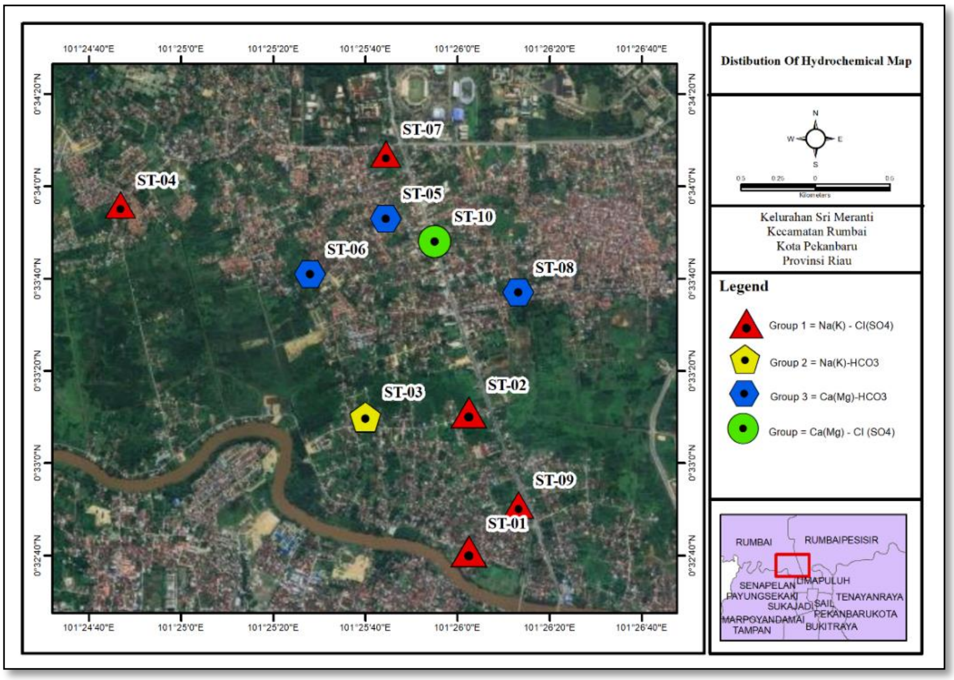

Fig 9. The distribution of hydrochemical facies in the study area

From the result of plotting 10 sample data on the Piper diagram, it was found that the study area predominantly falls into facies with sodium or calcium cations, while the anions consist of two types, namely chloride and bicarbonate. In the Na(K)-Cl(SO_4) group, which is classified as Group 1, several sampling locations such as ST-01, ST-02, ST-04, and ST-07 are included. The Na(K)-Cl(SO_4) composition is a result of mineral dissolution or ion exchange within the aquifer, which leads to a combination of Na(K)-Cl(SO_4). This composition may also be influenced by human activities, such as domestic, agricultural, or industrial waste, which contribute to increasing the ion content in groundwater.

In the Na(K)-HCO3 group which is included in group 2, it consists of several sampling locations in ST-03. The results of Na(K)-HCO3 were found in the recharge zone or shallow aquifer area. In the hydrogeological process, groundwater experiences the dissolution of minerals such as calcite or feldspar and in ion exchange in the aquifer system with clay minerals, Na ions can replace Ca and Mg ions, thereby increasing the sodium concentration. In this area, it usually comes from areas that have rainwater infiltration or water catchment.

In the Ca(Mg)-HCO3 group which is included in group 3, it consists of several sampling locations at ST-05, ST-06 and ST-08. The results of Ca(Mg)-HCO3 are the result of the dissolution of carbonate rocks. These results show that groundwater has interacted with carbonate rocks such as limestone or dolomite and This is included in the infiltration zone. Usually this type of groundwater is found in the infiltration zone, where the groundwater is relatively young and has not been affected by further chemical processes. experienced longer contact with rock and often experiences concentrations of dissolved substances. From the influence of geochemical processes in the evaporite solution, the presence of CI and SO4 indicates interaction with evaporite rocks such as halite or gypsum. Anthropogenic contaminants with high concentrations of Ci and CO4 also come from domestic, agricultural or industrial waste and discharge zones indicate that groundwater comes from zones that have gone through an ion enrichment process through the dissolution of rocks or minerals (Fig 9)

4. Conclusion

From the results obtained, conclusions are drawn on the analysis of the physical and chemical properties of groundwater, where the physical properties of several research stations are not suitable for use according to water quality standards, such as at stations ST-01, ST-02, ST-03, ST- 04, ST-05 and ST-09 which are not suitable for use according to water quality standards, ST-06, ST-07, ST-08 and ST-09 which are suitable for use according to water quality standards from the Ministry of Health.

Based on chemical properties standardized by the Ministry of Health, such as the pH value of water still meets the standard of 7.7, Na+ with an average of all stations is 20.49 Mg/l which still meets the standard, HCO3- with an average of all stations is 59.63 Mg/l l still meets the standard, CI- with the average of all stations is 19.75 Mg/l still meets the standard, SO42- with the average of all stations is 2.81 Mg/l still meets the standard. So based on its chemical properties it still meets quality standards but this ground water is influenced by the physical properties of ground water which is not suitable for use in some locations. Groundwater in the study area is divided into 3 groups, namely Type Na(K)-CI(SO4) is at locations ST-01, ST-02, ST-04, ST-07 and ST-04. The Na(K)-HCO3 type is at location ST-03. The Ca(Mg)-HCO3 type is at locations ST-05, ST-06 and ST-08. Type Ca(Mg)-There(SO4) is at location ST-10

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