Water Quality of Assessment of Angacha –Doyo area, Central Ethiopia Region, Ethiopia

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Rock-water interaction has an impact on the chemistry of groundwater, which in turn affects groundwater quality. The study area is located in the Kembata Tembaro zone in Angacha Woreda Bedena kebele, central Ethiopia, where the surface water is unsafe for drinking. Hence, the area mainly depends on groundwater for drinking purposes. The main objective of the study is to assess the water quality of the study area. Five water sample chemistry data sets were collected from the central Ethiopia region. The data was analyzed using IBM SPSS Statistics version 29, Excel, ArcGIS 10.3, and Grapher software. The dominant cations with mean values are Ca^{2+} (18.89 mg/L) > Na^{+} (17.76 mg/L) > K^{+} (7.99 mg/L) > Mg^{2+} (5.20 mg/L), and the dominant anions are HCO_3^- (129.1 mg/L) > Cl^- (5.33 mg/L) > SO_4^{2-} (4.33 mg/L). From the Piper and Durov diagrams, the water type of the area is Ca-Na-HCO_3 and Ca-Na-Mg-HCO_3, which results from rock-water interaction. Based on Pearson's correlation results, TDS is highly correlated with Na^+, Cl^-, and SO_4^{2-}, which contribute to the salinity of the groundwater. According to WHO standards and the water quality index, the water type is suitable for drinking purposes with excellent water quality. The water quality index is a very important tool for assessing the water quality of groundwater for different purposes.

Keywords: Groundwater, groundwater quality, groundwater facies, statistical analysis, Water quality index

Introduction

Background of the study

Water is one of the most essential substances needed to sustain human life, animals, plants, and other living things. There are different water bodies, among the different water bodies groundwater is found underground in the earth at different depths. Fresh water is essential in many spheres of human life in which groundwater accounts for 90% of all liquid freshwater (Liu et al., 2022)[1]. Groundwater is one of the reliable and vital sources of drinking water because of its widespread availability, occurring in natural conditions and less susceptible to water contamination as compared to freshwater (Wagh et al., 2016)[2]

Due to increasing population growth, human water demand for domestic, industrial, and agricultural purposes to supply adequate food for the nation is increasing (Watkins, 2006)[3] Ethiopia has always been characterized by high hydrological variability, compounded by the almost total absence of water storage and highly vulnerable watershed because of its geography and climate (Aberra, 2009)[4].The groundwater quality of Ethiopia shows large variation, ranging from fresh waters in many of the springs issuing from the crystalline basement rocks to more saline waters in parts of the Rift and the sedimentary formations of the plains.

Groundwater quality includes the physical, chemical, and biological properties of groundwater. Temperature, turbidity, color, taste, and odor make up the list of physical water quality parameters(Harter, 2003a)[5]. The chemical parameters include major ions(calcium, magnesium, sodium, potassium chloride, sulfate, and bicarbonate) whereas the biological includes microorganisms such as bacteria and viruses The chemical water quality of groundwater is the result of a hydrogeochemical process of solution and minerals (Appelo & Postma, 2004)[6]. The hydrogeochemical process is affected by precipitation, rock-water interaction, the structure of the geology, the minerals in the aquifer, and human activities. (Freeze & Cherry, 1979)[7]

People are very concerned about water quality since it has a direct impact on their health. Both natural and man-made factors, including household, industrial, and agricultural runoff, have an impact on it. (Simeonov et al., 2003)[8] Thus, water Quality evaluation of the groundwater is evaluated based on physical and chemical parameters Water Quality Index (WQI), a well-known method for assessing water quality offers a simple, stable, and reproducible unit of measurement and communicates information of water quality to the concerned body. (Singh et al., 2013)[9]. The water quality of groundwater can be assessed by using the water quality index (WQI).

The application of WQI helps the decision-makers in the possibility of successful management of WQ and supplies more details about the WQ for various uses by public people (Yenugu et al., 2020)[10]

Problems Statement and rational

In the study area, most of the perennial rivers are randomly used by the surrounding community without any rules with activities such as washing, bathing, irrigation, and cattle feeding, therefore the water quality of these rivers cannot be considered as potable water. Water such as rivers was not considered as a potential water source. It is due to not meeting hygienic standards and not being permanent resources due to seasonal fluctuations. So, Groundwater is essential to secure the safety of the water supply in the Angacha–Doyo area but little information is documented or studied about the chemistry and the Quality of the groundwater. The area practices a mixed-crop livestock farming system. The crop farming uses fertilizer that may pollute the groundwater and the livestock and human waste has also impact on the quality in which the area has no specified waste management area. Water quality is a major concern for people because it is directly associated with human well-being. Thus, this study aimed to assess water quality spectra and the current status of the groundwater based on hydrochemistry. This study was to fill the gap related to groundwater chemistry and quality, which other researchers used as a benchmark.

Significance and purpose

The output of this study work is very important to see the full picture of the current water quality status of the groundwater that was not determined previously by including all basic water quality parameters (physical and chemicals) for sustainable management of water regarding water quality. It is also used as a benchmark to study the water quality of the groundwater by other researchers.

Objectives

Specific Objectives

- To assess the physical water quality status of the groundwater
- To assess chemical water quality status of the groundwater
- To identify the water type of the groundwater

Scope and Limitations

This study is devoted to assessing and analyzing the current water Quality status of the Angacha–Doyo area based on the physicochemical parameters not based on biological ones. The analysis was done by using five water samples due to unavailability of data.

Theoretical framework Groundwater is defined as water contained in the aquifer matrix below the surface of the saturated zone, which naturally contains dissolved minerals. (Harter, 2003b; Siebert et al., 2010)[8,11]. Different hydrogeochemical process determines different physicochemical characteristics of groundwater, particularly in the zone of saturation (Bhuiyan et al., 2016). For viability, the administration and evaluation of groundwater assets need a comprehension of the hydrogeochemical and hydrogeological highlights of the groundwater aquifer (Azhar et al., 2015)[12]. As groundwater quality is affected by several factors, an appropriate study of groundwater aquifer characteristics is an essential step to state a supportable utilization of groundwater resources for future development and requirements (Yenugu et al., 2020)[10]. When groundwater moves through the rocks and subsurface soil, it has the opportunity to dissolve various sources of substances and contaminants (Yousefi et al., 2018)[13]. The total dissolved solid describes small amounts of inorganic salts and organic matter present in the water. The knowledge about the hydrochemistry of the water is essential to evaluating groundwater quality in any place (Srinivas et al., 2013)[9]. The groundwater quality deterioration is critical due to geogenic and human-induced activities (Krishnan & Saravanan, 2022)[14]. The water quality index is considered to be the most effective method to evaluate water quality (Sadat-Noori et al., 2014)[15]. Groundwater chemistry depends on several factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water, and inputs from sources other than water-rock interaction. (Güler & Thyne, 2004; Vázquez-Suñé et al., 2005)[16,17]. The groundwater quality parameters used for the assessment of groundwater quality are categorized into two levels. The Level 1 parameters (core parameters) - pH, electrical conductivity (EC), and nitrate (NO_3), provide essential information on acidification, salinization, and nutrient enrichment due to pollution by human activities, including agriculture and waste disposal, respectively. The Level Two parameters compromise Major cations.

Materials and Methods

Study Area Description

The study area is found in the central Ethiopia region Kembata Tembaro zone in Angacha Woreda Bedena kebele 2351m above sea level. The main water-bearing formation in the area is moderately to highly fractured and weathered Ignimbrite. The mean annual rainfall is 1656 mm with a bimodal pattern that extends from February to September. The rainy seasons are April, July, August, and September. The mean annual maximum temperature is an average 24 °C and the monthly temperature is 23 to 24 °C. The mean annual minimum temperature is 14 0C and monthly values range between 13 and 14 0C. The geology of the area under investigation consists of three- to four-dimensional and quaternary Rhyolite and basalt volcanic rocks covered by quaternary alluvial deposits and pre-Cambrian underground gneiss and granite. Quaternary volcanic rocks such as

Pitchstone, Pumice and Obsidian outcrops are among the most important quaternary volcanic rocks.

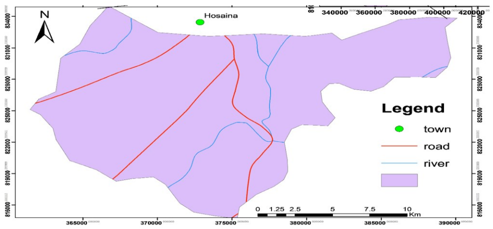


Fig. 1 Location Map of the study area

Data Collection

A total of five groundwater samples were collected from the central Ethiopia water office. The data contain water chemistry parameters such as pH, EC, TDS, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, total hardness, and total alkalinity. A total of five water samples were chosen because the area had five functional boreholes providing community water. Before collecting the water, groundwater was pumped to remove any stagnant water. The sampling bottle was rinsed with the sampled water to prevent contamination, and the water was acidified with sulfuric acid to preserve the chemical reactions.

Accuracy of Laboratory Analysis

Before conducting the analysis, the charge balance error (CBE) should be checked. The standard threshold limit for the charge balance error (CBE) is ±10% (Shuaibu et al., 2024)[18]. The charge balance error is used to judge the validity and quality of water analyses. It is a critical assessment that verifies the electrical neutrality of a water sample, ensuring that the analytical processes have been accurately executed.

The CBE of the sample was found to be below 10%, which is acceptable. The charge balance error is calculated using the following equation:

$$\text{Charge Balance Error (CBE)} = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100 \quad (1)$$

Statistical Analysis

Pearson's correlation of physicochemical parameters and the levels of metals in groundwater water were assessed using IBM SPSS Statistics version 29, and graphs were plotted using Grapher software and Excel, and ArcGIS version 10.3 was used to prepare a location map of the study area.

Water Quality Index (WQI)

This research objective is to assess the water quality of the Kembata Tembaro zone in Angacha Woreda Bedena kebele, central Ethiopia by employing which has not been extensively explored in previous studies. .The study integrates a wide range of physicochemical parameters to develop a robust WQI tailored for groundwater analysis and comparison of the results with WHO standards, providing a global benchmark for groundwater quality that has been largely overlooked in the current literature. By doing so, we identify critical discrepancies and potential health risks associated with groundwater consumption in the study area.

The water quality index is a quantitative measure used to determine the suitability of water for different purposes.(Adimalla et al., 2018)[13] WQI is a simple expression to represent the general quality of water as there are a variety of physical, chemical, and biological water quality parameters.

The methods to calculate the water quality index are as follows (Bascaron, 1979)[7]:

1. Identify the Parameters: The parameters used to calculate the water quality index are pH, TDS, Na, K, Ca, Mg, Cl, SO_4, NO_3, total hardness, and total alkalinity.
2. Determination of the Weightage
3. Determination of Sub-Indices
4. Integration of Sub-Indices in a Mathematical Formula

Results and Discussion

Physicochemical parameters of water

As shown in Table 01.

Total hardness

Total hardness is the sum of calcium and magnesium concentration, both expressed as calcium carbonate, in milligrams per liter. The hardness of water can be determined based on these concentrations of calcium carbonate: Below 75 mg/L - is generally considered soft. 76 to 150 mg/L - moderately hardness out of the six samples one sample is moderate hardness with the value of 91. The others are soft water with values below 75.

Electrical Conductivity

Conductivity is the ability of water to conduct current. It is sensitive to variations in dissolved solids, mainly mineral salts. Conductivity is expressed as micro siemens per centimeter (S cm-1) and, for a given water body, is related to the concentrations of total dissolved solids and major ions. One of the

Table 1 Physicochemical parameters of water

Sample ID	pH	EC	TDS	Na	K	Ca	Mg	Cl	SO_4	HCO_3	PO_4	NO_3	Total Hardness	Alkalinity
GW01	6.54	182.4	100.3	11.4	6.4	10.82	6.49	3.0	1.5	105.6	0.2	1.0	54.08	86.5
GW02	6.42	22.4	123.0	15.2	8.5	15.00	5.28	3.9	1.78	122.6	0.4	0.2	62.00	100.5
GW03	6.47	198.8	109.3	15.2	7.5	21.44	2.50	4.8	3.0	113.1	0.4	0.1	64.00	92.7
GW04	6.84	390.0	215.0	26.0	8.76	24.48	7.34	8.95	12.73	156.0	0.4	1.14	91.80	127.9
GW05	6.57	247.0	135.7	21.0	8.8	21.72	4.41	6.0	2.64	148.6	0.16	0.62	71.40	121.8

essential indicators for evaluating the quality of water is electrical conductivity. Since the composition of mineral salts affects the electrical conductivity of groundwater, it is important to understand the relationships between mineral salt composition and electrical conductivity (Tutmez et al., 2006)[19]

pH, acidity and alkalinity

The pH is an important variable in water quality assessment (Eyankware et al., 2020)[10] and the pH is an important variable in water quality assessment and It affects a variety of chemical and biological activities that occur in a body of water. pH, also known as hydrogen ion activity, is determined by the dissolved chemical and shows how acidic or basic a solution is at a particular temperature.

A pH of 6.57 is slightly acidic, but it is still within the range considered safe for drinking water. However, it is important to note that the pH of groundwater can vary depending on the geological formations and the presence of dissolved minerals and alkalinity with a minimum value of 86.5 and a maximum value of 127.9.

TDS

Total dissolved solids (TDS) are the amount of organic and inorganic materials, such as metals, minerals, salts, and ions, dissolved in a particular volume of water. The TDS ranges from 100-215, below the maximum Value of 1000.

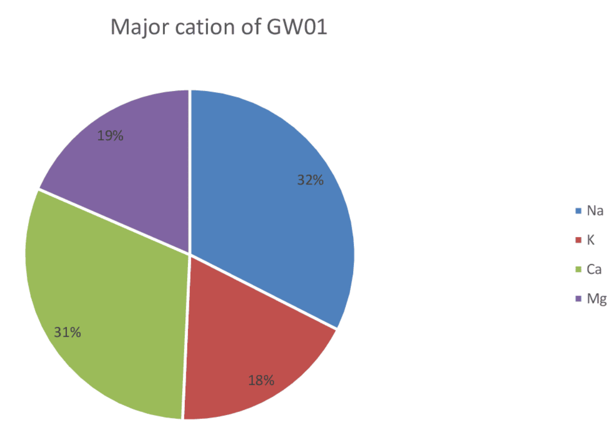
Major ions Concentration

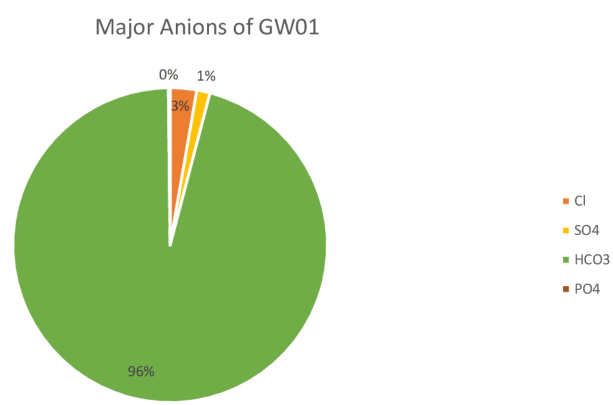
Major ions $(Ca^2+, Mg^2+, Na+, K+, Cl-, SO4^2-, HCO_3^-)$ are naturally variable in surface and ground waters due to local geological, climatic, and geographical conditions. The major ion concentration of each sample is plotted using a pip diagram.

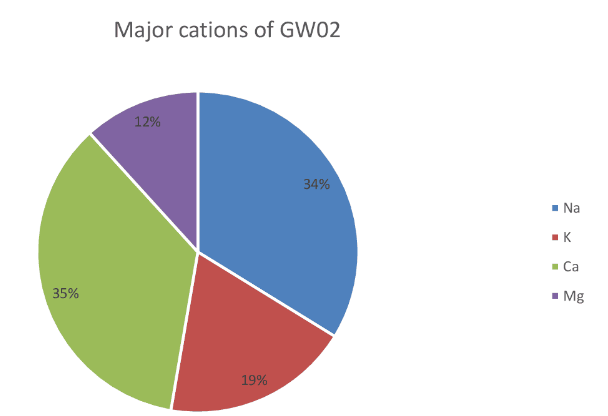
The most dominant dissolve cations in the study area are Ca and Na and the most common anion is bicarbonate.

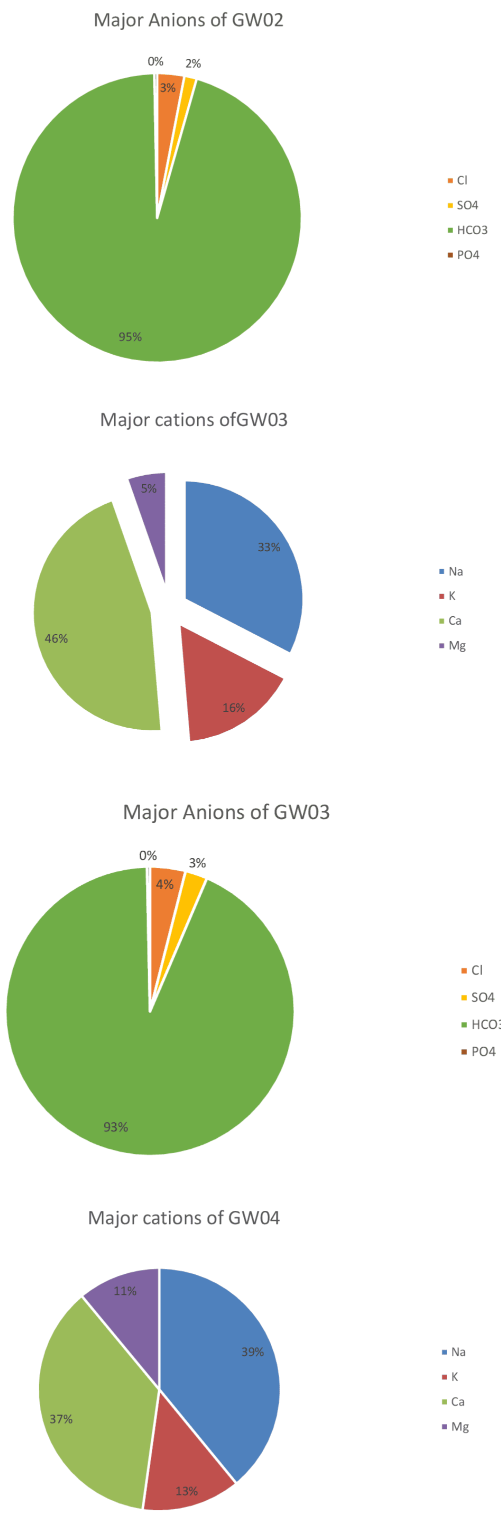
Descriptive Statistics of the Groundwater

The pH levels of the groundwater samples range from 6.42 to 6.84, which is generally considered suitable for drinking water. Total dissolved solids (TDS) and electrical conductivity (EC)









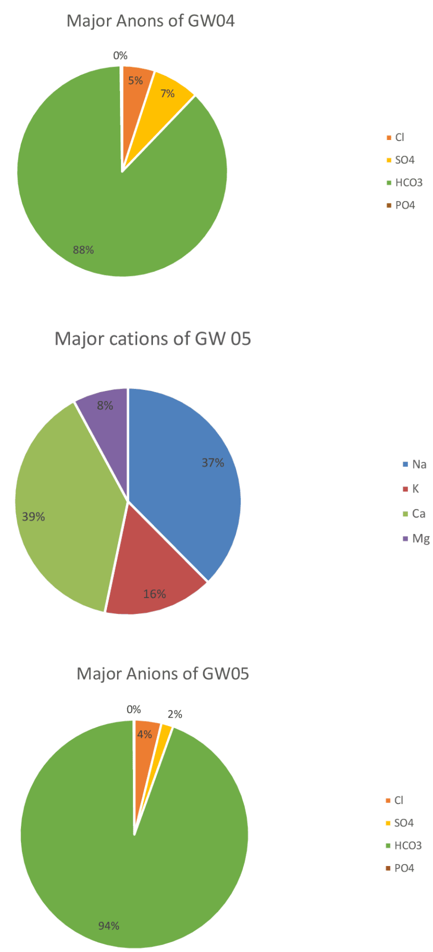


Fig. 2 Pie chart of major ions of samples

Table 2 Table 2. From the descriptive statistics data, all the parameters fulfill the WHO standards.

Parameters	Range	Min	Max	Mean	Std. Error	WHO Standards (mg/L)
PH	0.42	6.42	6.84	6.5680	0.07290	6.5-8
EC	207.6	182.4	390.0	248.440	37.0567	-
TDS	114.7	100.3	215.0	136.660	20.4882	1000
Na	14.6	11.4	26.0	17.760	2.5686	200
K	2.40	6.40	8.80	7.9920	0.46245	-
Ca	13.66	10.82	24.48	18.8920	2.44168	75
Mg	4.84	2.50	7.34	5.2040	0.84155	50
Cl	5.95	3.00	8.95	5.3300	1.03218	250
HCO3	50.48	105.55	156.03	129.1760	9.89568	-
PO4	0.24	0.16	0.40	0.3120	0.05426	-
NO3	1.04	0.10	1.14	0.6120	0.20752	50
Total Hardness	37.72	54.08	91.80	68.6560	6.40943	-
Alkalinity	41.4	86.5	127.9	105.880	8.1135	-
SO4	11.23	1.50	12.73	4.3300	2.11774	250

range from low to moderate, with GW04 having relatively highest TDS recorded. The amounts of potassium and sodium are within normal levels. Nitrate levels are low, which indicates acceptable water quality and little agricultural runoff, whereas anions like chloride and sulfate are still quite low, indicating little pollution. Total hardness and alkalinity show fluctuation, altering flavor and buffering capacity, which are vital for both human consumption and ecological health. Overall, the quality of the groundwater seems appropriate for agricultural and drinking purposes, but ongoing monitoring is required to handle any new issues that may arise.

Pearson's Correlation

The quality of water was characterized by various physicochemical parameters. These parameters change widely due to many factors like source of water, type of pollution, and seasonal fluctuations. The correlation analysis of the physicochemical properties of groundwater gives a fairly good amount of information like their correlation of each water quality parameter. The most widely used measures of monotone connection are Pearson's, Spearman's, and Kendall's correlation coefficients; the latter two are typically recommended for data that is not normally distributed.

The more commonly used Pearson's r is a measure of linear correlation, which is one specific type of monotonic correlation (Chok, 2010). If the data lie exactly along a straight line with a positive slope, then r = 1. The correlation coefficient (Pearson 'r') has been calculated between each pair of water quality parameters by using an IBM SPSS spreadsheet for the collected data.

The correlation coefficient 'r' has a value from -1 to 1. A negative sign represents that the two variables do not have a similar trend of variation whereas a positive value represents a similar trend. More will be the accuracy of fitness if r is closer to unity. A zero value indicates that "X" and "Y" have no relationship and are independent of one another.

Correlation between different pairs of water quality parameters for different water samples collected at different places of groundwater provides an idea about the hydrochemistry of the water resources. Statistical approaches were carried out in this study, to assess the water quality trends in the study area. Value with $r > 0.75$ is highly correlated like TDS, with EC, Na, Cl, SO4, that the salinity of groundwater is mainly dependent on Na, Cl and SO4 and value between 0.5-0.75 medium correlates like TDS with K, Ca, and Mg. The one with a value below 0.5 is less correlated.

Hydrochemical facies

Hydrochemical facies (Water Type) are a term used in this paper to denote the diagnostic chemical aspects of groundwater solution occurring in the hydrologic system (SEABER & Trenton, 1962)[20].The water's flow pattern and the reaction of chemical processes taking place inside the lithologic framework are both reflected in the facies. Hydrochemical facies were constructed using Grapher software by plotting piper and Drove diagrams. The Piper diagram is a graphical representation of the chemical composition of water samples. It is used to classify water types based on the relative proportions of major cations (calcium, magnesium, sodium, and potassium) and anions (chloride, sulfate, and bicarbonate). The diagram is divided into three sections: a diamond for cations, a triangle for anions, and a connecting line that represents the overall water type. From the Piper and drove diagram, the water type of the area is mixed water type Ca-Na-HCO_3 and Ca-Na-Mg-HCO_3 which is the result of rock water interaction.

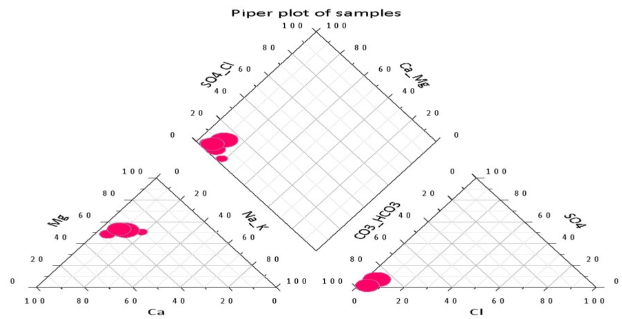


Fig. 3 Piper diagram of the samples

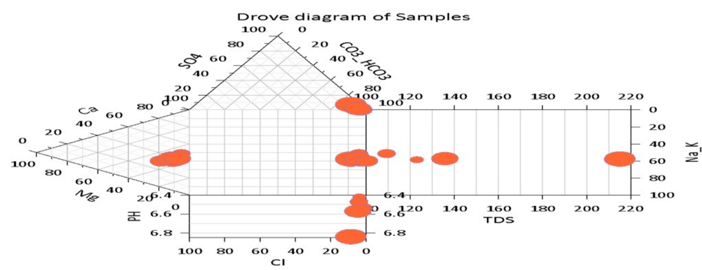


Fig. 4 Drove diagram of the samples

Water quality index

Bascaron water quality index results were influenced by the weightage as well as the sensitivity of the parameters. The parameters that have values far above and far below the WHO standards influenced the index value more (Menberu et al., 2021)[21]

According to (Bascaron, 1979)[7] water quality can be categorized based on the index as shown in Table 09.

A single value or index can be created from large amounts of water quality data using the water quality index (Uddin et al., 2021)[21]. The results of the water quality index can be utilized to assist planners and decision-makers in choosing the best GW management strategies(Al-Khashman & Jaradat, 2014)[22]. A water quality index (WQI) summarizes large amounts of water quality data into simple terms (e.g., excellent, good, bad, etc.) for reporting to managers and the public consistently (Diop et al., 2023)[23]. According to the results, every sample has exceptional groundwater quality, which is crucial for managing groundwater.

Table 3 Pearson's Correlation

	PH	EC	TDS	Na	Ca	Mg	Cl	SO_4	PO_4	NO_3	HCO_3	Total Hardness	Alkalinity
PH	1												
EC	0.904	1											
TDS	0.905	0.99999	1										
Na	0.816	0.93055	0.9298	1									
K	0.338	0.65559	0.6533	0.801	1								
Ca	0.542	0.69862	0.698	0.8564		1							
Mg	0.65	0.5627	0.5634	0.314	-0.1898	1							
Cl	0.874	0.94984	0.9498	0.9776	0.86729	0.318	1						
SO_4	0.923	0.99447	0.9947	0.8903	0.63178	0.63	0.922	1					
PO_4	0.065	0.33705	0.3374	0.1774	0.35313	-0.073	0.272	0.339	1				
NO_3	0.806	0.55003	0.5514	0.401	-0.0268	0.851	0.437	0.608	-0.353	1			
HCO_3	0.731	0.85802	0.8567	0.9687	0.77332	0.328	0.897	0.81	0.006	0.39	1		
Total Hardness	0.872	0.97441	0.9743	0.9757	0.83749	0.376	0.994	0.95	0.324	0.44	0.9	1	
Alkalinity	0.731	0.85809	0.8568	0.9688	0.77353	0.327	0.897	0.81	0.006	0.39	1	0.8970437	1

Table 4 The water quality index of sample number one

Sample ID	Parameters	S_i	$1/S_i$	K	w_i	W_i	M_i	M_i/S_i	Q_i	WQI
GW01	PH	8.5	0.117647	0.771605	0.09077705	0.090777	6.54	0.769412	76.94118	6.984493
	TDS	500	0.002	0.771605	0.00154321	0.001543	100.3	0.2006	20.06	0.030957
	NA	200	0.005	0.771605	0.00385802	0.003858	11.4	0.057	5.7	0.021991
	K	12	0.083333	0.771605	0.06430041	0.0643	6.4	0.533333	53.33333	3.429355
	Ca	75	0.013333	0.771605	0.01028807	0.010288	10.82	0.144267	14.42667	0.148422
	Mg	30	0.033333	0.771605	0.02572016	0.02572	6.49	0.216333	21.63333	0.556413
	Cl	250	0.004	0.771605	0.00308642	0.003086	3	0.012	1.2	0.003704
	SO4	200	0.005	0.771605	0.00385802	0.003858	1.5	0.0075	0.75	0.002894
	NO3	45	0.022222	0.771605	0.01714678	0.017147	1	0.022222	2.222222	0.038104
	Total hardness	200	0.005	0.771605	0.00385802	0.003858	54.08	0.2704	27.04	0.104321
	Total Alkalinity	200	0.005	0.771605	0.00385802	0.003858	86.5	0.4325	43.25	0.16686
	Total									11.48751

Ionic Ratio

It is possible to determine calcite, dolomite dissolution, and silicate weathering using the Ca^{2+}/Mg^{2+} molar ratio. $Ca^{2+}/Mg^{2+} = 1$ denotes the dissolution of dolomite, $Ca^{2+}/Mg^{2+} > 2$ denotes the dissolution of silicate, and values between 1 and 2 denote the dissolution of calcite[?]. The Ca^{2+}/Mg^{2+} ratio in the study shows values between 1 and 2, as well as values greater than 2, indicating that silicate weathering and, to a small extent, calcite dissolution are the primary processes.

The chloride–alkaline index (CAI) is an important tool for explaining the chemical processes of ion exchange between groundwater and its geological environment. A negative CAI value suggests an exchange of alkaline earth metals (Ca^{2+} and Mg^{2+}) from rock minerals with the presence of alkali metal ions (Na^+ and K^+) in groundwater. This exchange causes an influx of Ca^{2+} and Mg^{2+} ions into the groundwater system, leading to a subsequent rise in their concentrations[9].

$$\text{CAI-1} = \frac{Cl^- - (Na^+ + K^+)}{Cl^-} \tag{2}$$

$$\text{CAI-2} = \frac{Cl^- - (Na^+ + K^+)}{SO_4^{2-} + HCO_3^- + NO_3^-} \tag{3}$$

In the area, CAI-1 and CAI-2 are negative, which shows that Na^+ and K^+ in the surrounding rock have been exchanged by Ca^{2+} and Mg^{2+} in water.

Table 5 Water quality index of sample number two

Sample ID	Parameters	S_i	$1/S_i$	K	w_i	W_i	M_i	M_i/S_i	Q_i	WQI
GW02	PH	8.5	0.117647	0.771605	0.090777	0.090777	6.54	0.755294	75.52941	6.856337
	TDS	500	0.002	0.771605	0.001543	0.001543	123	0.246	24.6	0.037963
	NA	200	0.005	0.771605	0.003858	0.003858	15.2	0.076	7.6	0.029321
	K	12	0.083333	0.771605	0.0643	0.0643	8.5	0.708333	70.83333	4.554612
	Ca	75	0.013333	0.771605	0.010288	0.010288	16	0.213333	21.33333	0.219479
	Mg	30	0.033333	0.771605	0.02572	0.02572	5.25	0.175	17.5	0.450103
	Cl	250	0.004	0.771605	0.003086	0.003086	3.9	0.0156	1.56	0.004815
	SO4	200	0.005	0.771605	0.003858	0.003858	1.78	0.0089	0.89	0.003434
	NO3	45	0.022222	0.771605	0.017147	0.017147	0.2	0.004444	0.444444	0.007621
	Total hardness	200	0.005	0.771605	0.003858	0.003858	54.08	0.2704	27.04	0.104321
	Total Alkalinity	200	0.005	0.771605	0.003858	0.003858	86.5	0.4325	43.25	0.16686
	Total									12.43487

Table 6 The water quality index of sample number three

Sample ID	Parameters	S_i	$1/S_i$	K	w_i	W_i	M_i	M_i/S_i	Q_i	WQI
GW03	PH	8.5	0.117647	0.771605	0.090777	0.090777	6.47	0.761176	76.11765	6.909736
	TDS	500	0.002	0.771605	0.001543	0.001543	109.3	0.2186	21.86	0.033735
	NA	200	0.005	0.771605	0.003858	0.003858	15.2	0.076	7.6	0.029321
	K	12	0.083333	0.771605	0.0643	0.0643	7.5	0.625	62.5	4.018776
	Ca	75	0.013333	0.771605	0.010288	0.010288	21.44	0.285867	28.58667	0.294102
	Mg	30	0.033333	0.771605	0.02572	0.02572	2.5	0.083333	8.333333	0.214335
	Cl	250	0.004	0.771605	0.003086	0.003086	4.8	0.0192	1.92	0.005926
	SO4	200	0.005	0.771605	0.003858	0.003858	3	0.015	1.5	0.005787
	NO3	45	0.022222	0.771605	0.017147	0.017147	0.1	0.002222	0.222222	0.00381
	Total hardness	200	0.005	0.771605	0.003858	0.003858	64	0.32	32	0.123457
	Total Alkalinity	200	0.005	0.771605	0.003858	0.003858	92.7	0.4635	46.35	0.178819
	Total									12.43487

Table 7 The water quality index of sample number four

Sample ID	Parameters	S_i	$1/S_i$	K	w_i	W_i	M_i	M_i/S_i	Q_i	WQI
GW04	PH	8.5	0.117647	0.771605	0.090777	0.090777	6.84	0.804706	80.47059	7.304883
	TDS	500	0.002	0.771605	0.001543	0.001543	215	0.43	43	0.066358
	NA	200	0.005	0.771605	0.003858	0.003858	26	0.13	13	0.050154
	K	12	0.083333	0.771605	0.0643	0.0643	8.76	0.73	73	4.69393
	Ca	75	0.013333	0.771605	0.010288	0.010288	24.48	0.3264	32.64	0.335802
	Mg	30	0.033333	0.771605	0.02572	0.02572	7.34	0.244667	24.46667	0.629287
	Cl	250	0.004	0.771605	0.003086	0.003086	8.95	0.0358	3.58	0.011049
	SO4	200	0.005	0.771605	0.003858	0.003858	12.73	0.06365	6.365	0.024556
	NO3	45	0.022222	0.771605	0.017147	0.017147	1.14	0.025333	2.533333	0.043439
	Total hardness	200	0.005	0.771605	0.003858	0.003858	91.8	0.459	45.9	0.177083
	Total Alkalinity	200	0.005	0.771605	0.003858	0.003858	127.9	0.6395	63.95	0.246721
	Total									13.58326

Table 8 The water quality index of sample number three

Sample ID	Parameters	Si	1/Si	K	wi	Wi	Mi	Mi/Si	Qi	WQI
GW05	PH	8.5	0.117647	0.771605	0.090777	0.090777	6.57	0.772941	77.29412	7.016532
	TDS	500	0.002	0.771605	0.001543	0.001543	135.7	0.2714	27.14	0.041883
	NA	200	0.005	0.771605	0.003858	0.003858	21	0.105	10.5	0.040509
	K	12	0.083333	0.771605	0.0643	0.0643	8.8	0.733333	73.33333	4.715364
	Ca	75	0.013333	0.771605	0.010288	0.010288	21.72	0.2896	28.96	0.297942
	Mg	30	0.033333	0.771605	0.02572	0.02572	4.41	0.147	14.7	0.378086
	Cl	250	0.004	0.771605	0.003086	0.003086	6	0.024	2.4	0.007407
	SO4	200	0.005	0.771605	0.003858	0.003858	2.64	0.0132	1.32	0.005093
	NO3	45	0.022222	0.771605	0.017147	0.017147	0.62	0.013778	1.377778	0.023624
	Total hardness	200	0.005	0.771605	0.003858	0.003858	71.4	0.357	35.7	0.137731
	Total Alkalinity	200	0.005	0.771605	0.003858	0.003858	121.8	0.609	60.9	0.234954
									Total	**12.89913**

Where S_i is a standard value,

M_i is the measured value,

$$k = \frac{1}{\sum \frac{1}{S_i}},$$

$$W_i = \frac{w_i}{\sum w_i},$$

$$Q_i = 100\left(\frac{M_i}{S_i}\right),$$

$$WQI = \sum W_i Q_i.$$

Table 9 Categorization of water quality

WQI Rating	Classification
0-25	Excellent
25-50	Slightly polluted (Good)
50-75	Moderately polluted (Poor)
75-100	Polluted (Very Poor)
>100	Excessively polluted (Unsuitable)

Table 10 Water quality index of samples

Sample ID	Water Quality Index
GW01	11.49
GW02	12.43
GW03	12.43
GW04	13.58
GW05	12.89

The plot for Na versus Cl shows that many samples fall below the line of Na: Cl ratio equal to 1 indicating chloride source is other than the halite dissolution.

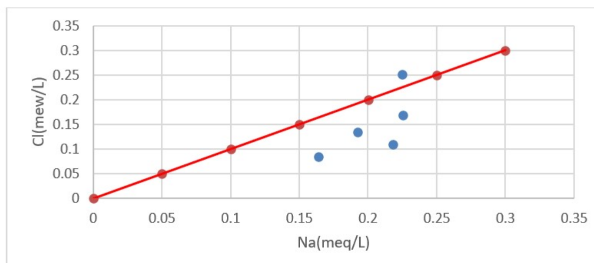


Fig. 5 Na versus Cl

Conclusion

From the analysis, the pH of the groundwater samples is slightly acidic, with a mean of 6.57 within the acceptable range. The electrical conductivity (EC) and total dissolved solids (TDS) are relatively low, with means of 248.44 and 136.66, respectively. This suggests that the groundwater is not saline. The concentrations of various ions such as Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Sulfate (SO_4), Bicarbonate (HCO_3), Phosphate (PO_4), Nitrate (NO_3), and Fluoride (F), are also relatively low. This suggests that the groundwater is not contaminated with various dissolved salts. The total hardness and alkalinity of the water samples are also relatively low, which suggests that the water is soft and has low buffering capacity. Overall, the chemical composition of the groundwater samples suggests that the water quality is good. Based on the water quality index and WHO standards, all samples have excellent water quality.

The findings have significant implications for policymakers and stakeholders, enabling more informed decision-making and the development of targeted strategies to ensure safe and sustainable groundwater resources. It is recommended to do further research by including other methodologies and data.

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