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GROUNDWATER QUALITY ASSESSMENT FOR RESIDENTIAL AND IRRIGATION PURPOSES: A CASE STUDY OF FUTUK AND ITS ENVIRONS, NORTHERN BENUE TROUGH, NORTHEAST NIGERIA

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ABSTRACT

This research assesses the suitability of groundwater quality in the region for residential and agricultural use. To evaluate the water quality for domestic purposes, 15 samples of groundwater were taken and tested for various physicochemical parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulfate (SO4), chloride (Cl), bicarbonate (HCO3), carbonate (CO3), and nitrate (NO3). The quality of irrigation water was evaluated using several parameters: permeability index (PI), sodium absorption ratio (SAR), total hardness (TH), residual sodium carbonate (RSC), and water quality index (WQI). Piper diagrams, Gibbs diagrams, and the chloro-alkaline index were used to determine groundwater facie classification and ion exchange mechanisms. When compared to the WHO 2011 standard, the physiochemical parameters are within the appropriate limits, with the exception of EC and NO3, which revealed excessive values in some samples. All of the measured parameters are suitable for irrigation activities. According to the Kelly index, there is just one sample that is inappropriate for irrigation. The predominant groundwater type in the area is calcium chloride, with sodium chloride constituting the second most common groundwater facies. The hydrochemical mechanism that regulates the local groundwater chemistry is reverse ion exchange. This indicates a positive index, resulting from the exchange of sodium (Na) and potassium (K) in the groundwater with calcium (Ca) and magnesium (Mg) in the aquifer components.

Keywords: Hydrochemical facies, Physiochemical parameters, Residential water quality, Irrigation water quality, Groundwater

INTRODUCTION

Since majority of rely on agriculture for their livelihood, the country's economy is built on it. World Bank data from 2014 indicated that 23% of Nigeria's workforce is employed in the agricultural sector, which generates 33% of the country's GDP (FAO, 2014). From the time of Nigeria's independence in 1960 until the middle of the 1970s, the country's primary source of foreign exchange was from agriculture. During that period, Nigeria is the leading global producer of groundnuts, palm oil, and cocoa, additionally, the country is significant producer of maize, yam, millet, cassava, coconuts, citrus fruits, and sugar cane (Ladan, 2014). It is noteworthy that the agricultural sector was neglected in the early 1970s, when the focus shifted to oil revenues, the agricultural sector has been neglected and its economic contribution has diminished. Nigeria continues to be an agrarian nation due to its abundant natural resources, which include: (i) 68 million hectares of arable land, (ii) 12 million hectares of freshwater, and (iii) an ecological diversification that encourages the production of livestock, fisheries products, crops, and forestry (Arokoyo, 2012).

Nigeria's farming system is still mostly rainfed, making it unduly reliant on weather variations and remains largely subsistence based. Only one percent of the total planted area is used for irrigated agriculture (FAO-Aquastat, 2017). With numerous dam projects located around the nation, there is enormous potential for irrigation. But the majority of the dams are either abandoned or not utilized very much for irrigation (Yahaya, 2002). When compared to Asia, sub-Saharan Africa's agricultural usage of irrigation water has been marked by inefficiency and poor management (Nwa, 2003). Food insecurity in Nigeria's rural areas is significant, with 84.3% reported in some communities in the north and approximately 56% in the country's southwest (Akinyele, 2009). Despite its agricultural output capacity, the country heavily relies on imports to feed its increasing population. The only option in addressing rural poverty and food insecurity problem is to improve agricultural productivity in the country (Xie *et al*., 2017).

Despite its importance in job generation and economic progress, agriculture's potential in Nigeria has yet to be completely realized (USAID, 2005). With the government closing the border for food and other products, it is vital to use groundwater, the country's primary source of fresh water for irrigation. Monitoring groundwater quality is critical to water resource management, particularly in northern Nigeria's hot, semiarid terrain. Groundwater is today regarded as one of the most vital natural resources for agriculture, domestic use, and industry. Its conservation and monitoring have direct or indirect implications for economic development, human health, irrigation, and population increase.

Water Quality Indices (WQIs) are used to assess water quality, providing a helpful interpretation of the quality of irrigation water. Irrigation water quality is determined by the amount of salts in the water, which is one of the causes associated with water quality deterioration, which can diminish permeability, increase salinity, and expose the water to hazardous ions. Quality assessments for irrigation purposes are based on physicochemical factors measured using various approaches. Such approaches are appropriate and widely used to assess water quality for irrigation applications. Furthermore, to assess the validation of water for irrigation, the individual water quality criteria are insufficient since it might be limiting and frequently results in inadequate performance in the evaluation. Several other researches employ the weighted score of each variable to estimate a water quality index. Based on experience and judgment, WQIs such as the sodium adsorption ratio (SAR), irrigation water quality (IWQ), sodium percentage (Na %), permeability index (PI), Kelly index (KI), and residual sodium carbonate (RSC) can meet the requirements for adequate monitoring and evaluation of irrigation water suitability. The main purpose of WQIs is to identify waters based on their physical properties, uses, and chemical composition, as well as to govern their allocations. For this reason, the analytical parameters must be weighted and assembled. In this study, WQIs are employed to evaluate water quality.

Water is the most crucial life-sustaining ingredient for both plants and animals, and the majority of illnesses affecting plants and animals are water-related. Various water quality indices and indicators are currently being utilized to determine water quality and suitability for home, irrigational, and industrial applications. This study aims to assess the quality of water for home and irrigation applications prior to usage.

Location and Accessibility

The study area is located between latitudes: 09° 49′ 15″ N & 09° 53′ 15″ N and longitudes: 10° 52′ E & 10° 57′ E, covering an area of approximately 68.45 Km2 in Futuk town and surroundings, Alkaleri LGA, Bauchi State. It is accessible via tarred roads from Alkaleri to Futuk, Futuk to Kashere, and Futuk to Mansur, as well as several untarred roads (Fig. 1).

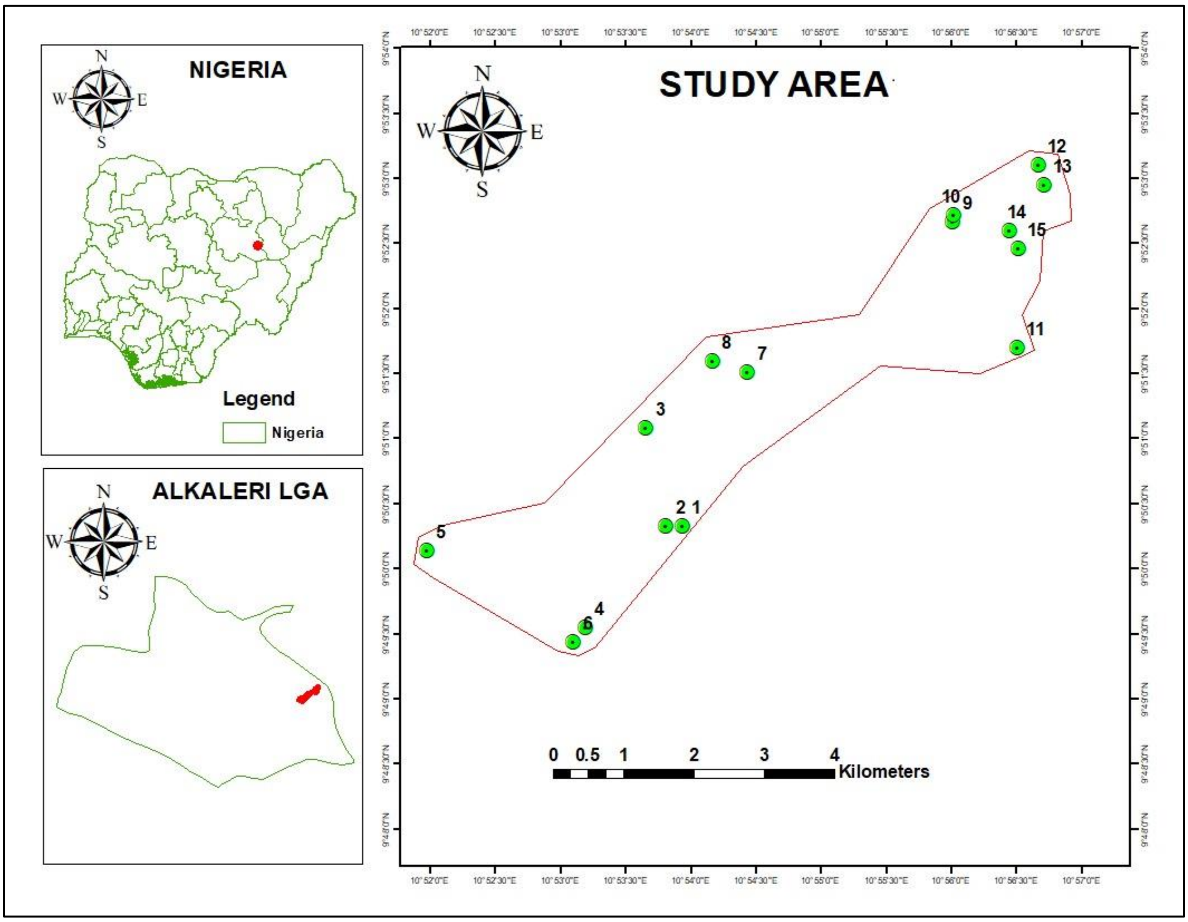

Figure 1: Location Map of the Study Area Showing Water Sampling Points

Climate and Relief

The climate in the area is tropical, with two distinct seasons: wet and dry. The dry season begins in November and last in March, while the wet season is from April to October. However, the southwestern part has considerable relief of up to 448 m above sea level, whereas the eastern portion has comparatively modest relief of about 375 m above sea level (Fig. 2).

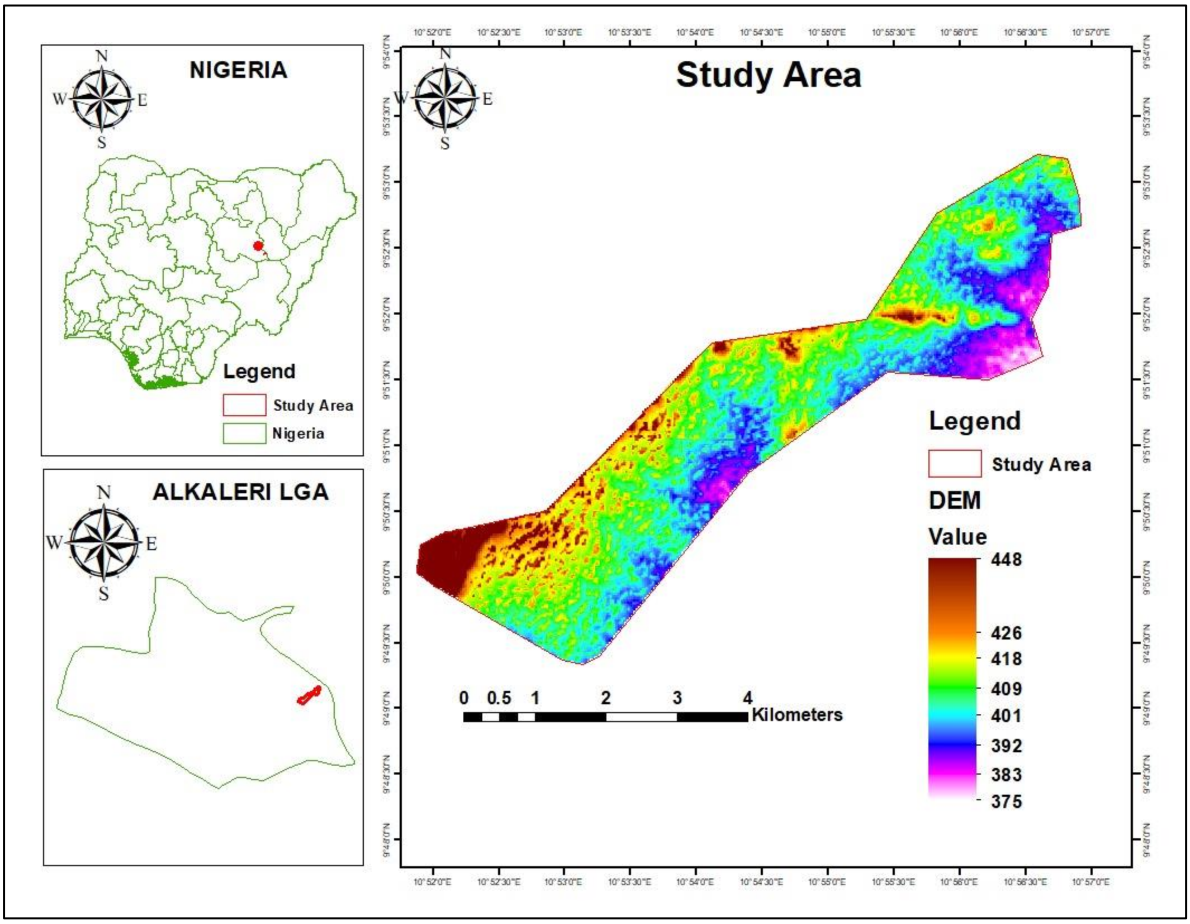

Figure 2: Digital Elevation Model of the Study Area

Geology

Pan-African Orogeny deformed rocks of Nigeria's Basement Complex around 550 million years ago, due to collisions of plate between the West African craton's passive continental margin and the active Pharusian continental margin. Comprehensive studies of these rocks' megascopic and microscopic features and mineralogical properties have been conducted by Falconer 1911, Carter et al 1963, Oyawoye 1972, Elueze 1982 and Obaje 2009. In various parts of Nigeria, these Basement Complex rocks are overlain by younger strata, forming sedimentary basins. The oldest exposed sedimentary rock in the study area is the Pindiga Formation, which conformably overlies the Yolde Formation. The Turonian–Santonian era's complete maritime intrusion into Upper Benue is represented by this formation and the Gongila Formation. Lithologically, these formations are distinguished by the intercalation of pale colored limestones, minor sandstones, and dark/black carbonaceous shales and limestones. The quarry of Ashaka Cement factory stands as type locality of Gongila Formation, while Pindiga village represents type locality for the Pindiga Formation. According to lithology, the Fika Shale is composed primarily of very fissile, bluish-greenish carbonaceous shales, occasionally light gypsiferous, and occasionally limestones. The typical locality of the formation, which is totally marine, is Nafada village. Obaje (2008).

The entire Benue Trough underwent folding and deformation during the Santonian period. The Maastrichtian Gombe Sandstone and the Tertiary Keri-Keri Formation are evidence for post-folding sediments. The Gombe Sandstone bears witness to the restoration of the Albian paleoenvironmental condition, as it shares lithological similarities with the Bima Sandstone. On the other hand, there are extremely thick intercalations of coal, lignite, and coaly shale in the Gombe Sandstone Formation. It is typically composed of coal seam contacts and siltstone, shales, and ironstone intercalations (Obaje *et al*., 1999).

The Kerri–Kerri Formation is considered as continental sequence that was unconformably overlies the Gombe Sandstone Formation and was deposited under a variety of conditions, including alluvial, braided, and lacustrine. It is composed of siltstones, claystones, and pale gray sandstones, with the claystones making up the majority of the lithology in most areas. Carter et al 1963, identified the thickness in the adjoining Norther Benue Trough to be approximately 130 meters. Within the Gongola Basin, the youngest Cretaceous sedimentary rocks of the Northern Benue Trough are represented by the lacustrine to deltaic Gombe Formation, which in certain locations unconformably overlays the pre-mid-Santonian series. The Paleogene Kerri-Kerri Formation's continental sandstones, siltstones, and shales indicate the end of the Northern Benue Trough's sedimentation process, Abubakar *et al*. (2008).

The research area's geology is dominated by the Turonian Pindiga Formation and a younger Maastrichtian Gombe Formation deposited in the area's far north (Fig. 3).

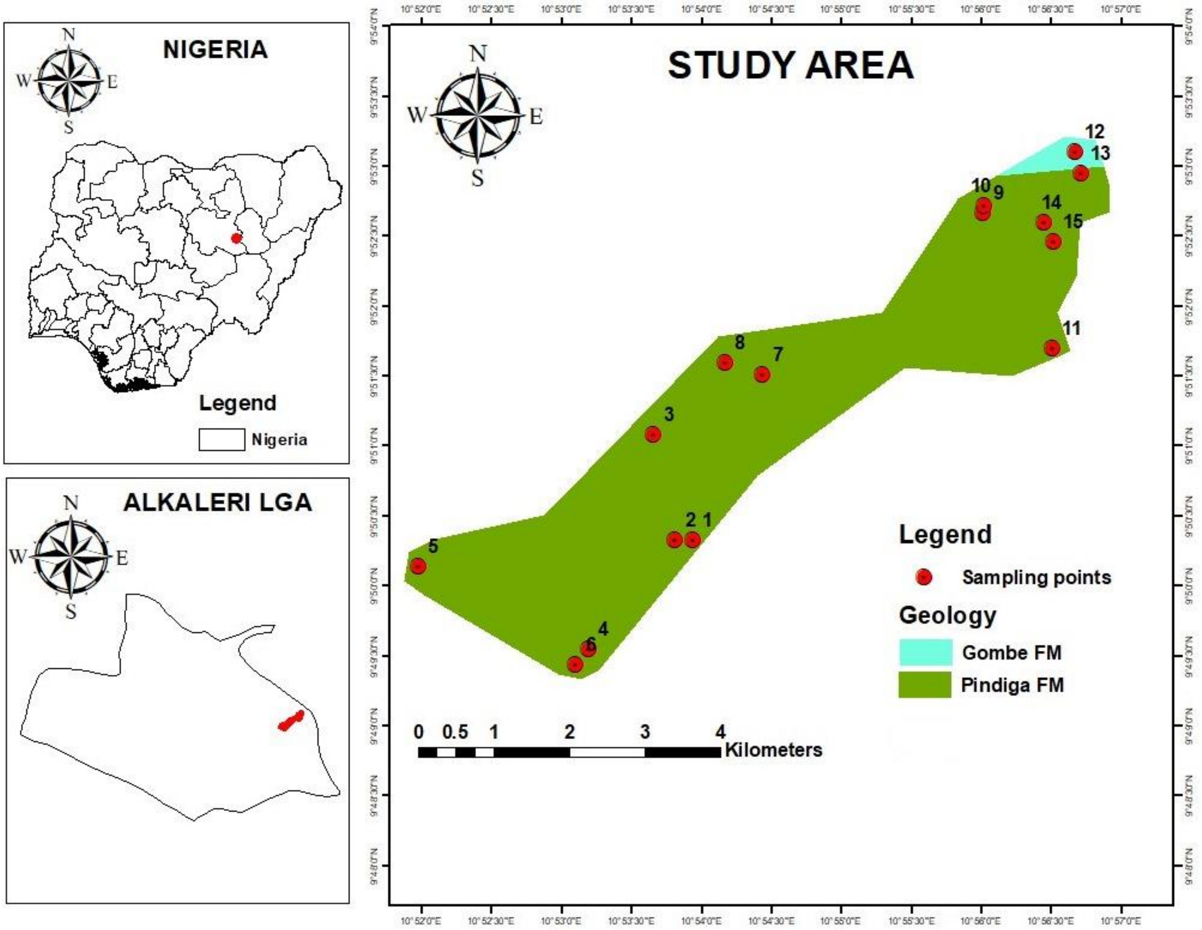

Figure 3: Geological Map of the Study Area

MATERIALS AND METHODS

In this study, 15 groundwater samples were collected in 1000 mL polyethylene bottles that had been rinsed with actual water samples from each well prior to collection and were stored in a refrigerator at 4°C. The samples were tested using conventional analytical methods. The chemical analysis was carried out with a variety of instruments and methodologies. The pH, TDS, and EC were measured in situ with a handheld pH/EC/TDS meter. Major cation parameters and heavy metal concentrations were determined using an inductively coupled atomic absorption spectrophotometer (ICPAES-Model No. IRIS INTREPID II XSP-Thermo Electron Corporation), chemical parameters, HCO3 and Cl were measured by titration, and SO4 concentration was estimated using spectrophotometry. The minimum, maximum, average, and standard deviation values of the various elements of water samples were calculated.

The following equations were utilized to compute the groundwater quality of various parameters in the region.

Equations 1–4 were used to calculate the water quality index (WQI) (Oiste, 2014):

$$WQI = \sum_{i=1}^{n} SI_i \ldots \qquad (1)$$

For every parameter in this formula, the sub-index is displayed as SI_i.

$$SI = (W_i \; X \; q_i) \qquad (2)$$

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (3)$$

Where w_i is the weight of each parameter, and n is the number of parameter

$$q_i = \frac{C_i}{S_i} X \; 100 \qquad (4)$$

Where Si is the WHO standard, C_i is the concentration of each chemical characteristic for each water sample, and q_i is the quality rating.

Equation 5 was used to determine the area's sodium adsorption ratio.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \ldots \qquad (5)$$

Equation 6 was used to calculate the sodium percent.

$$\text{Na (\%)} = \frac{100(\text{Na}^{+} + \text{K}^{+})}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{+} + \text{K}^{+}} \qquad (6)$$

The residual sodium carbonate was calculated using Equation 7.

$$RSC = (CO_3^{-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \qquad (7)$$

Equations 8 and 9 were used to calculate total hardness.

$$TH = ca^{2+} \; X \; \frac{CaCO_3^{-}}{Ca^{2+}} + Mg^{2+} \; X \; \frac{CaCO_3^{-}}{Mg^{2+}} \ldots \qquad (8)$$

This expression can be simply written as,

$$TH = 2.5Ca^{2+} + 4.1Mg^{2+} \qquad (9)$$

Where TH, Ca^{2+} and Mg^{2+} Concentrations are all in mg/L (Todd, 1980).

Equation 10 was used to calculate the Permeability Index.

$$\text{PI} = \frac{\text{Na}^{+} + \sqrt{\text{HCO}_3^{-}}}{\text{Na}^{+} + \text{Ca}^{2+} + \text{Mg}^{2+}} \; \text{X } 100 \qquad (10)$$

The Kelly index was calculated using equation 11.

$$KI = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+})} \ldots \qquad (11)$$

Equations 12 and 13 were used to calculate Gibbs ratios.

$$Gibbs \; 1 = \frac{Cl^{-}}{Cl^{-} + HCO_3^{-}} \ldots \qquad (12)$$

$$Gibbs \; 2 = \frac{Na^{+}}{Na^{+} + Mg^{2+} + Ca^{2+}} \qquad (13)$$

Equations 14 and 15 were used to derive the chloro-alkaline index, which determines the ion exchange process.

$$CAI\ 1 = \frac{(Cl^- - (Na^{2+} + K^+))}{Cl^-} \ldots \quad (14)$$

$$CAI\ 2 = \frac{(Cl^- - (Na^+ + K^-))}{(HCO_3^- + CO_3^- + SO_3^{2-})} \ldots \quad (15)$$

RESULTS AND DISCUSSION

Characteristics of Drinking Water Quality

Physico-chemical characteristics of groundwater samples were statistically examined, and the mean, maximum, and lowest concentrations are shown in (Table 1). The study's minimum and maximum values for temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) vary from 18.0 to 38.60 ^{0}C, 5.7 to 7.62, 1.23 to 3220 µS/cm, and 64 to 2420, respectively. The major cations, Na^+, K^+, Ca^{2+}, and Mg^{2+}, have respective values of 0.007 to 0.36 mg/L, 0.03 to 1.76 mg/L, 0.00 to 9.39 mg/L, and 0.001 to 11.72, while the major anions, SO_4^{2-}, Cl^-, HCO_3^-, and CO_3^-, vary from 56.30 to 91.10 mg/L, 10.00 to 20.00 mg/L, 1.43 to 7.17 mg/L, and 6.06 to 30.32 mg/L.

The principal ions in groundwater are abundant in the following order: $SO_4^{2-} > CO_3^- > Cl^- > HCO_3^-$ and $Mg^+ > Ca^+ > K^+ > Na^+$ (Fig. 4). Table 1 compares the measured ions of the individual samples with the WHO (2011) allowed limits.

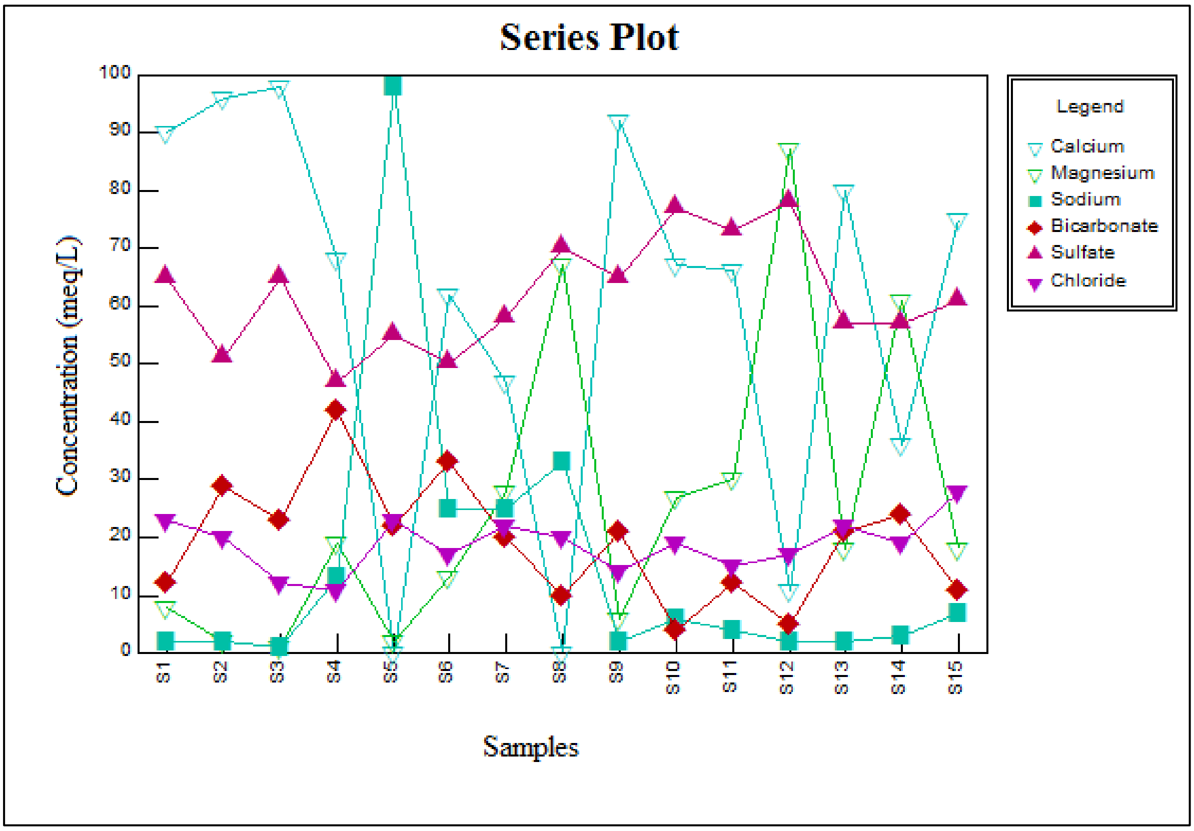

Figure 4: Series Plot showing concentration of ions in water

Table 1: Shows the lowest, maximum, and average values for the various components found in water samples

Parameter	Unit	Min.	Max.	Mean	Standard Deviation	WHO limit (2011)
pH		5.700	7.62	6.49	0.47	6.5-8.5
Temp	^{0}C	18.00	38.60	24.99	6.23	30
EC	µS/cm	123.0	3220	668.40	758.75	1500
TDS	Ppm	64.00	2420	484.27	610.73	1000
Ca	mg/L	0.000	9.39	3.46	3.00	100
Mg	mg/L	0.001	11.72	1.16	2.95	75
Na	mg/L	0.007	0.36	0.08	0.11	150
K	mg/L	0.030	1.76	0.36	0.53	12
SO_4	mg/L	56.30	91.10	67.84	9.74	250
Cl	mg/L	10.00	20.00	15.32	4.00	200
HCO_3	mg/L	1.43	7.17	3.60	1.75	300
CO_3	mg/L	6.04	30.32	15.20	7.403	240
NO_3	mg/L	10.00	60.00	31.33	18.46	50

Water Quality Assessment for Irrigation

Agriculture is a major source of income in the area, and one of the sources of water for irrigation uses is groundwater, especially during the peak of the dry season when the water table drops. A number of parameters were used to assess the water's suitability for irrigation, including total hardness (TH), permeability index (PI), Kelly index (KI), sodium absorption ratio (SAR), sodium percentage (Na%), residual sodium carbonate (RSC), and water quality index (WQI). Table 2 summarizes the water quality parameters.

Table 2: Shows the lowest, maximum, and average values for the various components found in water samples

Classification Pattern	Sample Range				Categories	Ranges	Description	Number of Samples	Sample (%)
	Min	Max	Mean	STDEV					
Sodium Absorption Ratio (SAR, meqL^{-1})	0.001	0.141	0.019	0.035	Excellent	<10	Don't have Sodium Hazard	15	100
					Good	10-18	Low Sodium Hazard	0	0
					Permissible	18-26	Harmful to Soil	0	0
					Unsuitable	>26	Unsuitable for Irrigation	0	0
Sodium Percent (Na %, meqL^{-1})	1.0	98.0	15.4	25.5	Excellent	<20	Excellent for Irrigation	11	73
					Good	20-40	Good for Irrigation	3	20
					Permissible	40-60	Permissible for Irrigation	0	0
					Doubtful	60-80	Doubtful for Irrigation	0	0
					Unsuitable	>80	Unsuitable for Irrigation	1	7
Residual Sodium Carbonate (RSC, meqL^{-1})	-1.02	0.85	0.21	0.45	Good	<1.25	Generally Safe for Irrigation	15	100
					Medium	1.25-2.5	Marginal as an Irrigation Source	0	0
					Bad	> 2.5	Usually Unsuitable for Irrigation without Amendment	0	0
Total Hardness (TH, ppm)	0.005	59.10	13.87	14.79	TH	0-75	Soft	15	100
					TH	75-150	Moderately Hard	0	0
					TH	150-300	Hard	0	0
					TH	>300	Very Hard	0	0
Permeability Index (PI, meqL^{-1})	28	21411	2141	5600.2	Class I	>75	Good for Irrigation	10	67
					Class II	25-75	Suitable for Irrigation	5	33
					Class III	<25	Unsuitable for Irrigation	0	0
Kelly's Index (KI, meqL^{-1})	0.002	10	0.69	2.575	KI	<14	Suitable	14	93
					KI	>1	Unsuitable	1	7
WQI (meqL^{-1})	7.543	63.31	17.91	13.853	Class I	<50	Excellent	14	93
					Class II	50-100	Good	1	7
					Class III	100-200	Poor	0	0
					Class IV	200-300	Very Poor	0	0
					Class V	>300	Unsuitable	0	0

Irrigation Water Quality (IWQ)

One of the key indicators in the study and quality control groundwater is irrigation water quality, which can be measured effectively to determine whether or not it is suitable for human consumption (Singh *et al*. 2011; Islam *et al*. 2017). The water quality index is calculated by taking into account the water's suitability for drinking and irrigation.

In order to determine the impact of agricultural and population density that directly affect the groundwater, WQI is utilized in this study to evaluate the quality of the local groundwater.

The weight (wi) allocated to each criterion is then decided by how significant it is to the overall quality of the water for irrigation and drinking. pH, electrical conductivity (EC), total dissolved solids (TDS), nitrates (NO3), total hardness (TH), magnesium (Mg), calcium (Ca), sodium (Na), potassium (K), bicarbonate (HCO3), sulfate (SO4), and chloride (Cl) were all considered (Table 3).

Table 3: Input used to compute the groundwater quality index

Parameter	Unit	Weight (wi)	Relative weight (Wi)
pH		3	0.075
EC	(μS/cm)	5	0.125
TDS	(ppm)	5	0.125
TH	(ppm)	2	0.05
Na	(meq/L)	3	0.075
K	(meq/L)	2	0.05
Mg	(meq/L)	3	0.075
Ca	(meq/L)	2	0.05

SO_4	(meq/L)	4	0.1
Cl	(meq/L)	4	0.1
HCO_3	(meq/L)	2	0.05
NO_3	(meq/L)	5	0.125
		Σwi=40	ΣWi=1.00

Table 2 shows that the WQI values are divided into five classes, with 93% of the sample being categorized as excellent water and 7% as good. Intensive farming practices that are linked to industrial and household wastewater and effluent sewage significantly contribute to groundwater pollution.

Sodium Absorption Ratio

An important metric for determining whether irrigated water is suitable for a sodium threat is the SAR. A water sample with an excessive amount of sodium in it decreases the permeability of the soil, which in turn limits the amount of water available to the plant because the sodium minimizes the size of the pore spaces in the soil. In sensitive plants, excessive salt absorption can result in sodium toxicity.

SAR is used to categorize irrigation water (WHO 1989). Therefore, when determining whether an area is suitable for irrigation, it is imperative to evaluate the sodium threat. Sodium adsorption ratio is one of the most crucial factors in assessing sodium toxicity (Todd and Mays 2005).

Each parameter's concentration is expressed in meq/L. The SAR values for the groundwater samples varied between 0.001 to 0.141, with an average value of 0.019, as shown in Table 1. The SAR values of the water samples from the examined area do not indicate a sodium problem, since they all lie below the range of <10 and are considered excellent for irrigation (Richards 1954). When deciding whether groundwater can be used for agriculture, EC and SAR collaborate. SAR (alkali hazard) and EC (salinity hazard) values are presented in a USSL (1954) diagram to assess whether water is suitable for agriculture. The graphic (Fig. 5) from the US Salinity Laboratory (Richards, 1954) shows that the water samples' salinity and alkalinity hazards classes were C1–S1 (13%), C2–S1 (53%), C3–S1 (27%), and C4–S1 (7%). The outcome demonstrates that most groundwater, like in C2-S1 and C3-S1, has a high salinity and a low salt content.

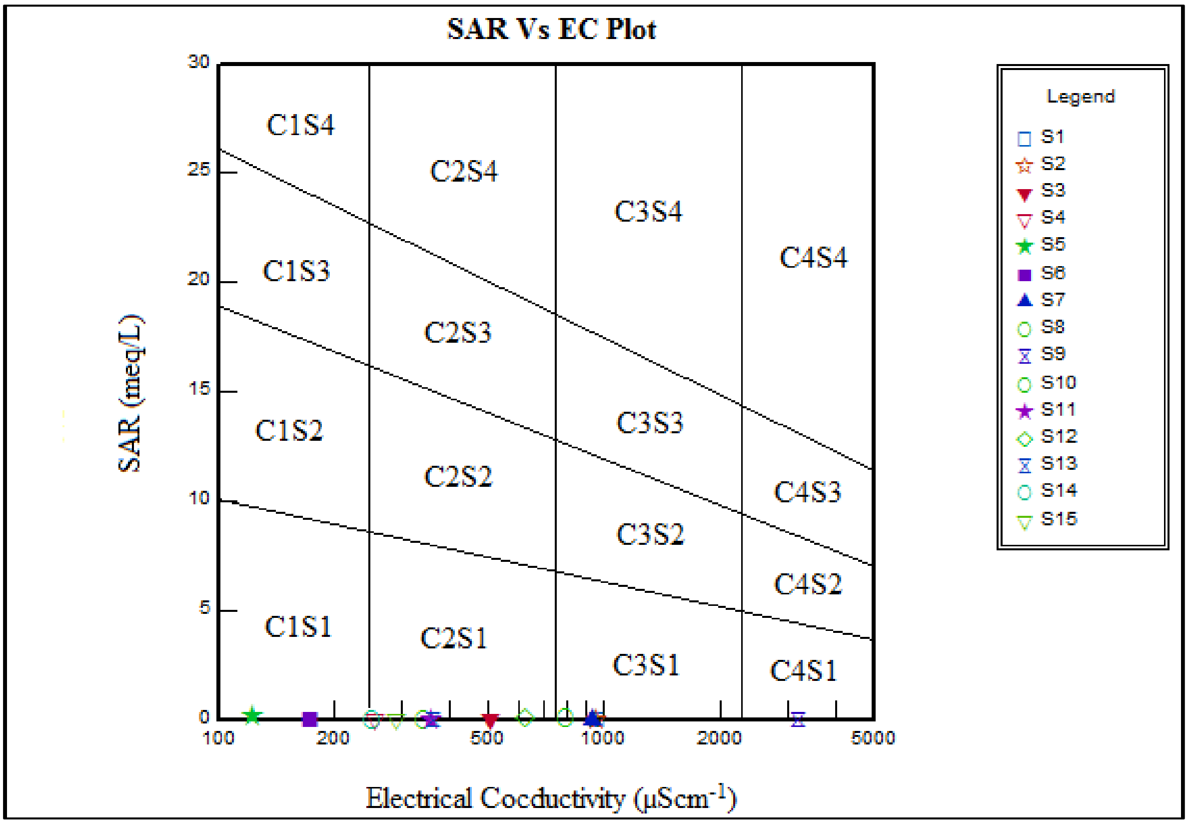

Figure 5: SAR Vs. EC water classification diagrams for irrigation purposes

Sodium Percentage (Na %)

Sodium concentration is another significant classification criteria for irrigation since it reacts with the aquifer, reducing its permeability. Alkali soils include a high concentration of sodium and have carbonate as the main anion, whereas saline soils have chloride or sulphate as the predominant anion. Sodium is important in the categorization of groundwater for irrigation because it reacts with soil, obstructing particles and limiting permeability (Todd, 1980; Domenico and Schwartz, 1990).

Percent sodium in water is a measure used to determine irrigation appropriateness (Wilcox, 1948). The sodium content in the area ranges from 1.0% to 98.0%, with an average of 15.4%. According to Na% values, the majority of water samples are excellent for irrigation (73%), while 20% are good and 7% are unsuitable.

Figure 6 shows a plot of sodium % versus electrical conductivity. It is clear that 60% of the water samples are very good to good, 26% are good to permitted, 7% are unsuitable, and the remaining 7% are inappropriate.

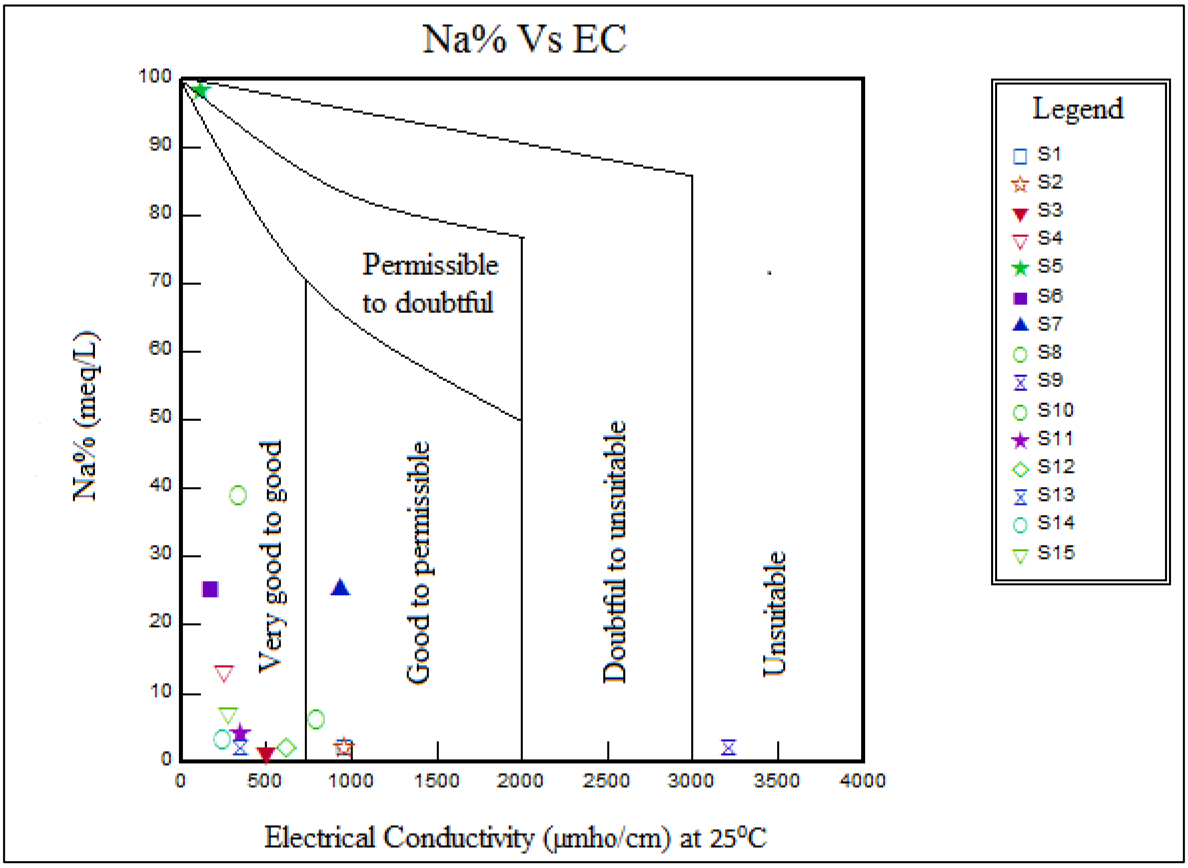

Figure 6: Wilcox diagram showing classification of water for irrigation based on Na % and EC.

Residual Sodium Carbonate

In soils where the concentration of HCO_3 and CO_3 is higher than that of Ca and Mg, the precipitation of Ca and Mg can cause deterioration to the soil's permeability. Residual sodium carbonate (RSC) is used to express a relationship between Ca and Mg and HCO_3 and CO_3. Moreover, Na% and SAR are employed to assess the water quality for agricultural uses (Li *et al*. 2016). The difference between weak acids and alkaline earths is used to determine the RSC (Eq. 7). The results indicate that the RSC values in the research location had a mean value of 0.21 and ranged from -1.02 to 0.85 (Table 2). All of the samples are classified as excellent by RSC, meaning they are all generally safe to drink.

The total hardness

High concentrations of calcium and magnesium ions, as well as occasionally other dissolved substances like iron, are characteristics of hard water. Because of the interaction between water and the rock framework, calcium typically enters the water as either calcium sulfate ($CaSO_4$) or calcium carbonate ($CaCO_3$). While dolomite ($CaMg(CO_3)_2$) is the main supplier of magnesium.

The study discovered that the average CaCO3 hardness of the water samples ranged between 0.005 and 59.10 mg/L. According to Table 2, all water samples were classified as soft (100%).

Permeability Index (PI)

In order to improve irrigation water quality, the permeability index (PI) is another essential indicator to consider when evaluating irrigation water quality in relation to soil. The permeability of soil can be impacted by the prolonged use of water for irrigation farming. It is affected by the soil's Na^+, Ca^{2+}, Mg^{2+}, and HCO_3 compositions. The samples exhibited PI values in the range of 28 meq/L to 21411 meq/L, with an average of 2141 meq/L. In general, PI is divided into three groups; 67% of the samples belong to class I, which is ideal for irrigation, and 33% of the samples are in class II, which is also appropriate for irrigation.

Kelly's Index (KI)

Kelly's index (KI) refers to the excess of sodium relative to calcium and magnesium. The index is used to assess whether groundwater is appropriate for irrigation. As Kelly (1963) stated.

The parameter concentrations are expressed in meq/L. In this study, the area's Kelly index averaged 0.69 meq/L and ranged from 0.02 to 10 meq/L. According to the KI results, 93% of the samples are appropriate for irrigation, whereas 7% are not.

Classification of Hydrochemical Processes

Piper Diagram

Pipers (1953) trilinear diagram for graphical analysis uses the notion of hydrochemical facies of the researched area to help comprehend the composition and chemical connection between dissolved ions in water (Fig. 7). The similarities and differences between the water samples are shown in this graphic (Todd 1980). The present investigation employed a piper trilinear diagram to ascertain the major ions, hydrochemical facies, and water type. The main anion is SO_4 and the cations are Ca and Mg. Ca & Mg are much greater than Na & K and Cl & SO_4 than HCO3 & CO_3 in groundwater samples. The primary cause of groundwater quality is the interaction between water and rock. The samples can be classified into two main groundwater facies according to where they are on the Piper diagram's diamond-shaped field. Up to 93% of the sample consisted of the calcium chloride (Ca-Cl) type of groundwater, which is the predominant kind in the area. Every sample from the region falls within the Ca–Cl groundwater type and is dominated by persistent hardness. Reverse ion exchange reactions can result in the formation of such water types. These fluids typically have quite high TDS as well because of the high Ca and Cl concentrations. The second groundwater facies, which makes up 7% of the water samples in the region, is of the sodium chloride (Na-Cl) type, which is representative of the evaporation processes that regulate the groundwater chemistry.

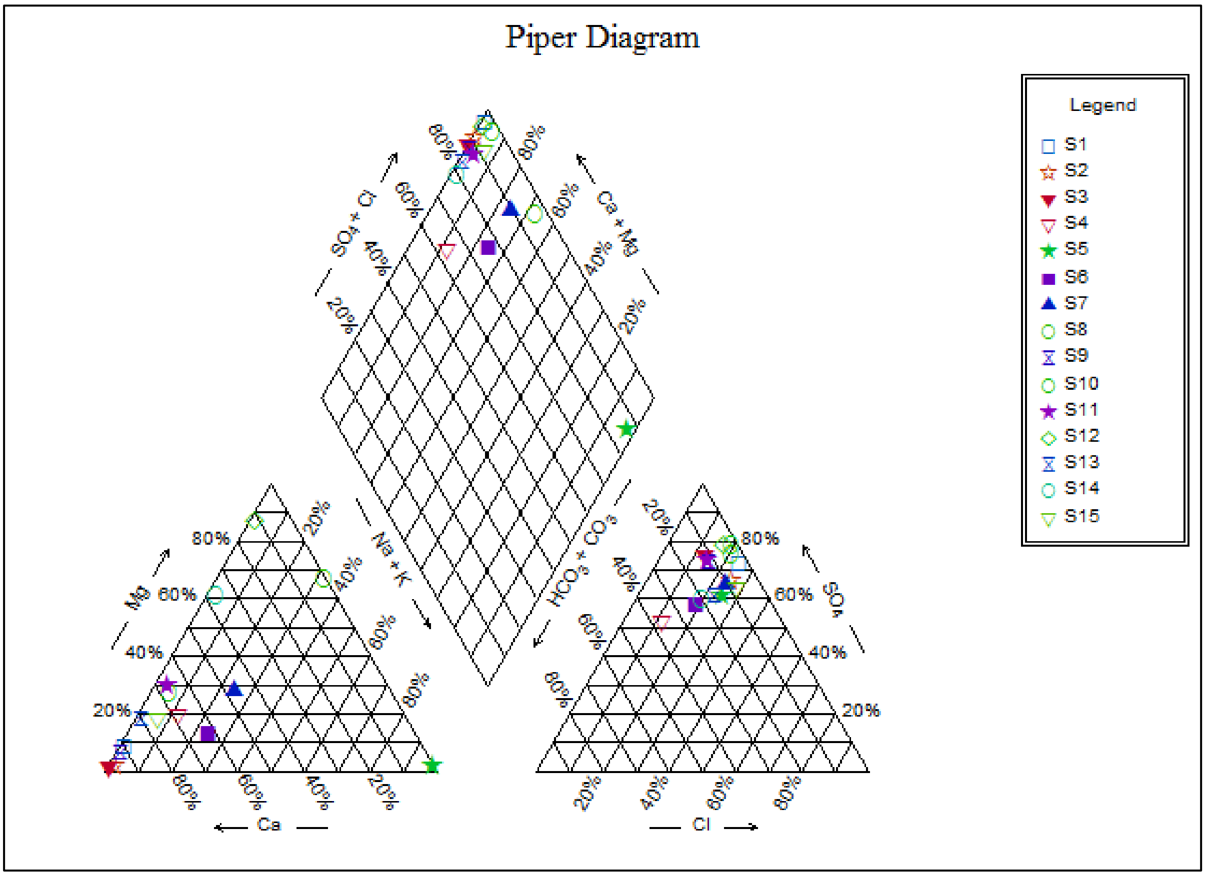

Figure 7: Piper Diagram for classifying groundwater facies

Gibbs diagrams

The Gibbs diagram, which illustrates the connection between aquifer lithology and groundwater chemistry, among other things, can be used to illustrate hydrochemical variability (Xu *et al*., 2019). Three primary natural mechanisms may be identified from this diagram: the dominance of precipitation, the dominance of rocks, and the dominance of evaporation. The hydrogeochemical processes and solute origins are depicted in the Gibbs diagram (Gibbs, 1970). The diagrams consist of a series of semi-logarithmic plots with TDS on the vertical axis and the ratio of anions and cations in Gibbs 1 and Gibbs 2 on the horizontal axis.

The majority of the samples, according to Gibbs diagrams (Fig. 8), are within the rock dominance, indicating that the primary mechanisms supplying ions to the local groundwater are rock weathering and water-rock interaction.

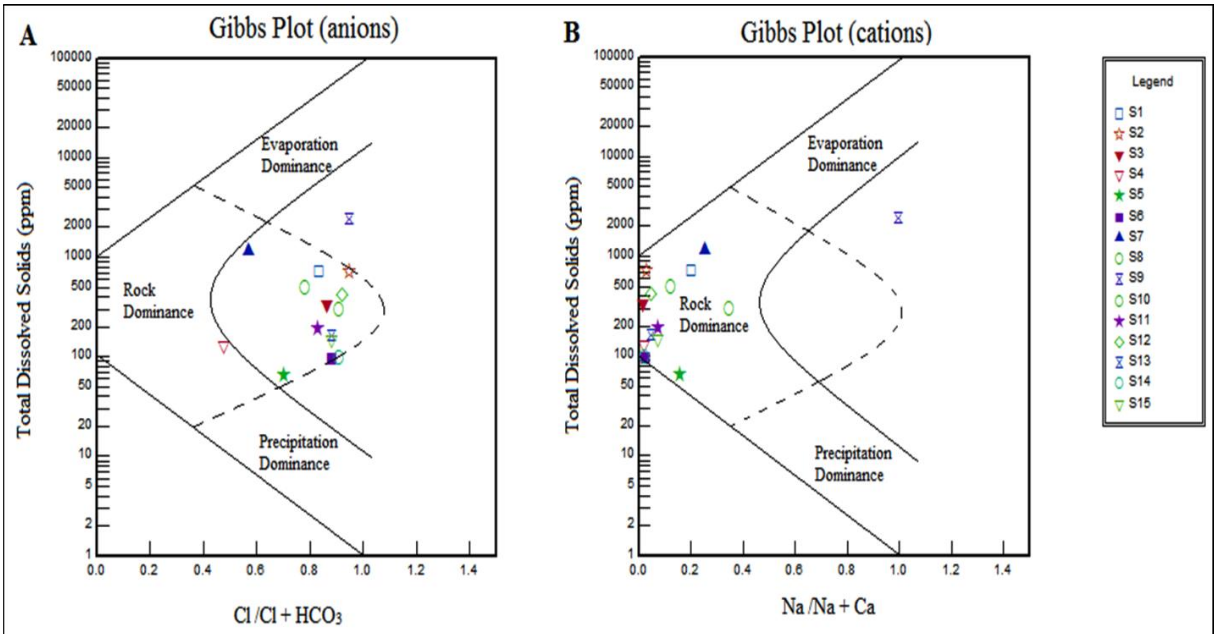

Figure 8: Gibbs Diagram, a) anions, b) cations

The process of ion exchange

Ion exchange is an important geochemical process that regulates the chemistry and quality of groundwater. The chloro-alkaline indices (Eqs. 14 and 15) were often utilized in meq/L to ascertain the ion exchange procedure. The indices offer important insights into the ion exchange interactions between the aquifer material and groundwater. By examining the chloro-alkaline indices, one can deduce the ion exchange that occurs between the groundwater and its surroundings during residence or percolation (Schoeller 1965, 1967). When Na and K from the groundwater interact with Ca and Mg from the aquifer material, a positive index is indicated by reverse ion exchange. Additionally, normal ion exchange produces a negative index when Na and K from the aquifer exchange with Ca and Mg from the groundwater. As a result, a reverse ion exchange exposes a positive quantity of CAI while a conventional ion exchange displays a negative amount.

The study's chloro-alkaline index results indicate that CAI 1 and CAI 2 range in value from 0.851 to 0.997 and 0.101 to 0.381, respectively. This demonstrates that the hydrochemical process governing the local groundwater chemistry is reverse ion exchange.

According to Figures 9 and 10, reverse ion exchange is the predominant geochemical process, as evidenced by the chloro-alkaline indices of the groundwater samples in the research area, which vary between 0.1 and 1.0.

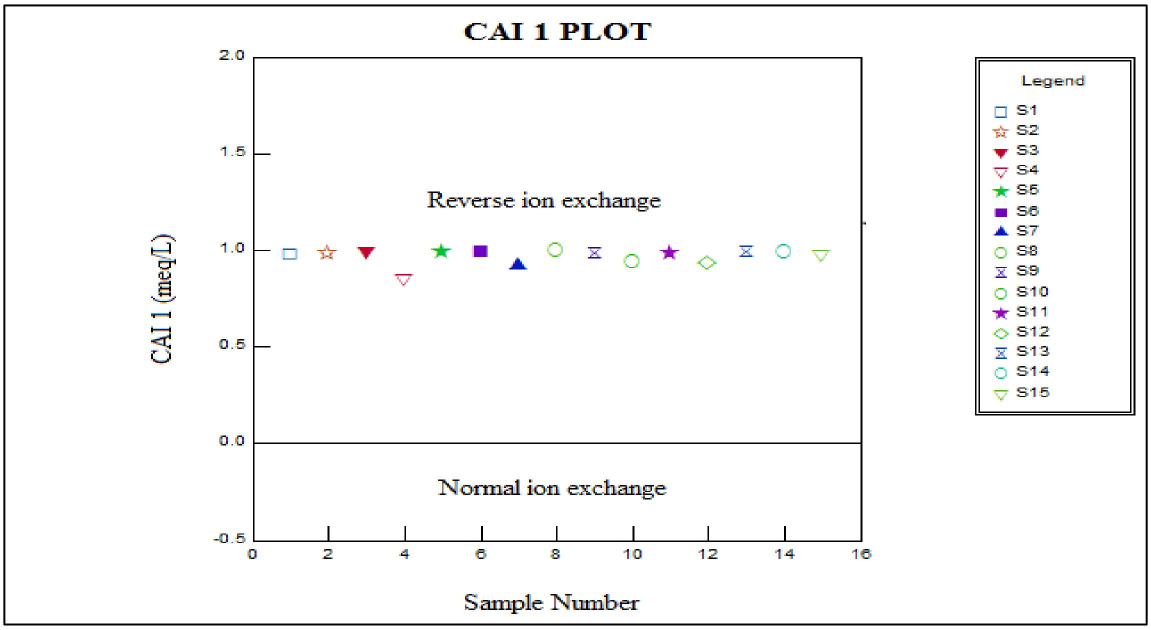

Figure 9: Chloro-Alkaline Index 1 (CAI 1)

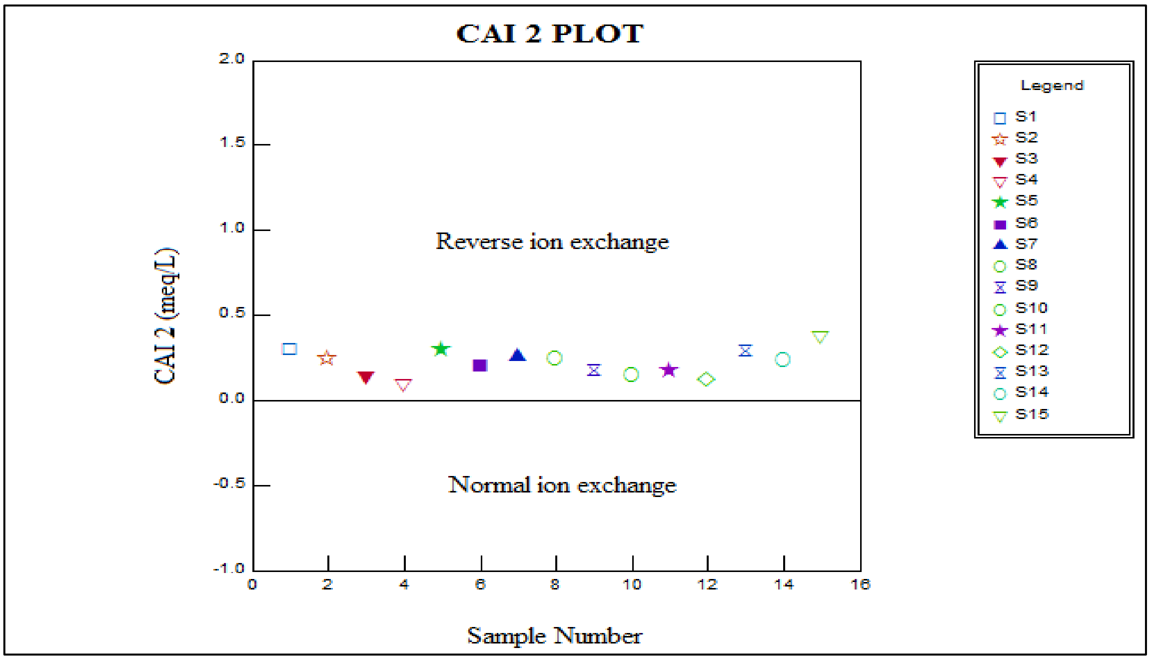

Figure 10: Chloro-Alkaline Index 2 (CAI 2)

CONCLUSION

In comparison with the WHO 2011, all the parameters are safe to drink, with the exception of electrical conductivity (EC) and nitrate (NO3) in certain samples. According to the irrigation water quality assessment, all of the samples have a total hardness (TH) of less than 0.5, an excellent sodium absorption ratio (SAR), a sodium percentage (Na%) that ranges from excellent to good for irrigation, residual sodium carbonate (RSC) that is generally safe for irrigation, a permeability index (PI) that is between suitable and good for irrigation, a water quality index (WQI) that is excellent to good for irrigation, and a Kelly index (KI) that is suitable for irrigation, with the exception of one sample that is not suitable for irrigation. The area's groundwater is distinguished by a greater rate of SO_4^{2-} than Cl^- and HCO_3^-, as well as a higher concentration of Ca^{2+} and Mg^{2+} than Na^+ and K^+. A cursory examination of the Piper plot revealed that the groundwater is categorized into two types: Ca-Cl and Na-Cl. Rock dominance, as demonstrated by Gibbs plots, indicates that the primary mechanisms supplying the area's groundwater with ions are rock weathering and water-rock interaction. The research area's groundwater is generally suitable for irrigation and residential use.

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