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Research Paper

Groundwater Quality Assessment in the Central Region of Ghana

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Abstract: In the central region of Ghana, a study that applied two water quality indicators and a risk index to groundwater was successfully completed. The weighted arithmetic water quality index (WAQWI), the water quality index (WQI), and the water quality risk index for human consumption (IRCA) were all employed in the study. In the research area, there are four different forms of groundwater: Ca-Mg-SO_4, Na-Cl, Ca-Mg-HCO_3, and mixed water. Rock weathering is the primary process regulating the chemical of the groundwater. Evaporation, ion exchange, and the effects of anthropogenic activities are other processes that may be controlling the geochemistry. According to the WQI, 6% of the groundwater samples had excellent quality, 54% had good quality, 22% had poor quality, 9% had very poor quality, and 9% were unfit for drinking without treatment. According to the WAQWI, 71% of groundwater are of outstanding quality, followed by 19% of acceptable quality, 4% of bad quality, and 6% of unsuitable quality. IRCA calculations showed that 2% of the samples included water that posed no risk to human health, 20% contained water that was low risk, 2% contained water that was medium risk, 75% contained water that was high risk, and 1% contained water that was unfit for human consumption. The IRCA indicates that there is a generally high level of health risk associated with using the groundwater for drinking without prior treatment, even though the two indices indicate that the groundwater is generally good for that purpose.

Keywords: *Groundwater, Water Quality Index, Weighted Arithmetic Water Quality Index, Water Quality Risk Index for Human Consumption, Central Region, Ghana, World Health Organization*

Introduction

Natural resources like water are crucial to human existence. For the general welfare, clean water is crucial. Since water reacts with and dissolves many chemicals from the atmosphere, surface, and subsurface, it does not exist in its purest form. The chemistry and general quality of water are altered due to the dissolution of gaseous chemicals in the atmosphere, organic materials, and inorganic materials from the earth's surface and subsurface (Raju, 2007; Wang, 2013). Different anthropogenic activities may have an impact on the chemistry and general quality of water supplies. Groundwater frequently has a distinct hydrochemistry and quality due to interactions between the water and its environment (Back, 1966; Drever, 1982). Ion exchange between water and the aquifer system, the dissolving of rock minerals and the effects of human activity are some of the ways that water interacts with its surroundings (Faure, 1998). It is important to keep in mind that even elements that are beneficial to human health when present in low quantities can have major negative effects on public health when present in high concentrations (Raju, 2012).

The practices of water safety are therefore required, which ensure that the entire water supply chain is watched to prevent water contamination or to discover pollution early enough to allow for remediation. The protection of the water source and the entire water supply chain is ensured by water safety procedures. Therefore, in order to effectively manage water resources, it is necessary to comprehend both the natural processes that control the chemistry and general quality of the water as well as the potential effects of human activity (Raju et al., 2011). Around two billion people lack access to suitable water sources on a global scale (UN, 2014, 2021). People use water from various sources for drinking and other domestic tasks including cooking, personal hygiene, washing utensils, etc. Water can come from either a surface or a subsurface source.

Unfortunately, using water of poor quality might harm a person's health. Water pollution influences the usage of the water for different purposes, necessitating effective water quality

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monitoring to assure water safety or early detection of contamination and remediation. This necessitates the use of an efficient monitoring tool, such as the Water Quality Index and the IRCA, which offer an efficient evaluation of the usage of the water resources for drinking (Torres et al., 2010; Castro et al., 2014). Water resources can get contaminated in a variety of ways, including through human activities and natural processes, and the contaminants can be either organic or inorganic. The WHO has released a water safety plan (WSP) for effective management of drinking water to enable risk assessment and proper management of water resources to satisfy the need for supplying high-quality water from the source to the consumer. The development of the water safety team, defining the current water system (DWSS), identifying hazards and risky events, assessing risks, and risk management planning are the five stages that typically make up the WSP (Perez et al., 2020).

Rural areas in underdeveloped nations like Ghana frequently lack access to sufficiently treated water for home use, so they supplement it with groundwater by drilling boreholes. To ensure that the public has access to safe water, this necessitates the efficient implementation of water safety measures. Due to the availability of groundwater, population growth, and the generally poor quality of surface water, groundwater use is increasing nowadays. According to statistics, 60% of the projected 982 km^3/year rate of groundwater extraction is used for agricultural activities, with the remaining 40% being used for drinking and domestic purposes (NGWA, 2016). However, in developing nations, more than 50% of the groundwater that is taken is used for drinking (NGWA, 2016).

People in the research area rely on groundwater for domestic and agricultural purposes, among other uses. The region's surface water bodies are becoming more and more polluted because of galamsey operations, making it harder to supply drinkable water. This necessitates the adoption of proper tools to assess the Region's water resources. Water safety practices are advised to ensure the appropriate management of the region's groundwater resources. Diverse professional organizations, including those involved with water, the environment, engineering, politics, public health, social science, and policymaking, must collaborate on this. Sadly, not all professionals are familiar with the idea of water quality. As a result, the gap between the water experts and the other stakeholders widens. An efficient method called the water quality index is utilized to close that gap (Shah and Joshi, 2017).

Examples of WQI include the National Sanitation Foundation index (NSF WQI method), the Weighted Arithmetic Water Quality Index (WAQWI) technique, the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), the Water Quality Index, and others. The Canadian Council of Environment Ministers created the CCME WQI to assess the ecological quality of water (Agarwal et al., 2020; Saffran et al., 2001). The WAQWI uses measures of regularly measured water quality to express the degree of purity (Tygai *et al.*, 2013). Though this tool employs fewer parameters than comparable WQIs, it nevertheless permits the use of several physical, chemical, and bacteriological properties of the water (Saha et al., 2019). The WQI tool has been used in numerous water studies throughout the world. The Canadian Council of Environment Ministers created the CCME WQI to assess the ecological quality of water (Agarwal et al., 2020; Saffran et al., 2001).

In his research, Agyemang (2019) used WQI methodologies to evaluate the drinking water quality in the Afigya Kwabre District. He noted that 80% fell into the "excellent" group, 7.5% into the "good," 5% into the "poor," and 7.5% into the "unsuitable" category. He blamed anthropogenic activities and the comparatively high quantities of iron and lead in the groundwater for the poor water quality in some localities. Again, Agyemang (2020) applied the method to determine if groundwater in Agona East District of Ghana was suitable for drinking and found that every water sample fell into the good category. Boah et al. (2015) used the WAQWI approach to evaluate the Vea Dam's water quality for drinking purposes in Ghana's Upper East Region and discovered that the area's water had a WAQWI value of 54.21, meaning it was unfit for consumption without prior treatment.

Out of these studies, 82% employed the techniques to characterize the quality of river water, while 18% applied the tools to characterize the other forms of water, such as groundwater for drinking, household use, and irrigation (Shah and Joshi, 2017; Ahmed et al., 2020; Uddin et al., 2021). The CCME WQI and NSF-WQI methodologies, according to Uddin et al. (2021), account for around 50% of all research conducted utilizing the WQI tool globally. While many researchers have found success using a single tool, some have integrated two or more of the many WQI techniques to assess the water quality (Finotti et al., 2015; Jahan and Strezov 2017; Sim & Tai, 2018; Zooalnoon & Musa 2019; Alexakis, 2020). Once more, the water quality risk index for human consumption is a useful technique to analyze the potability of water for human drinking and to determine the degree of risk of illness incidence associated with water consumption (Garcia-Avila *et al.*, 2022). The IRCA is a tool for determining if water is fit for human consumption. The allocated scores to the various parameters, which are established by Resolution 2115 of 2007, are used in the calculation of the IRCA (Duarte *et al.*, 2022).

Study area

The purpose of this study was to use the IRCA technique to analyse the amount of health risk related to drinking groundwater and two different water quality indices to determine whether the groundwater was suitable for consumption. The fact that some people in the Region drink untreated, raw groundwater makes the use of the IRCA in this study necessary. In order to manage water resources holistically, water quality indices method is particularly good in expressing the water quality. The tool may show the water resource's quality in time and space when used with the GIS approach (Kumar & Sharma, 2019; Kamboj & Kamboj 2019). In various locations of the world and for various purposes, different writers have evaluated water quality using various types of WQI (Nayak & Patil, 2015). The methods used to evaluate the water quality, and the numerous characteristics utilized for the index are what differentiate different water quality indices (Ahn *et al.*, 2018; Garcia-Avila *et al.*, 2018).

Materials and Methods

The Central Region is bordered by latitudes 5° 05' 48.484" N and 5° 56' 23.525" N, and longitudes 1° 49' 53.868" W and 0° 23' 59.586" W (Fig.1). The area is located in the evergreen and semi-deciduous forest zones of the dry equatorial climate region. The dry and wet seasons are the two predominant in the region with a typical annual rainfall range of 1000-2000 mm. The dry season runs from December to February while the wet seasons run from May to June as well as September to October. The average yearly temperature is between 24 ºC and 30 ºC, with the peak months being March and August, respectively.

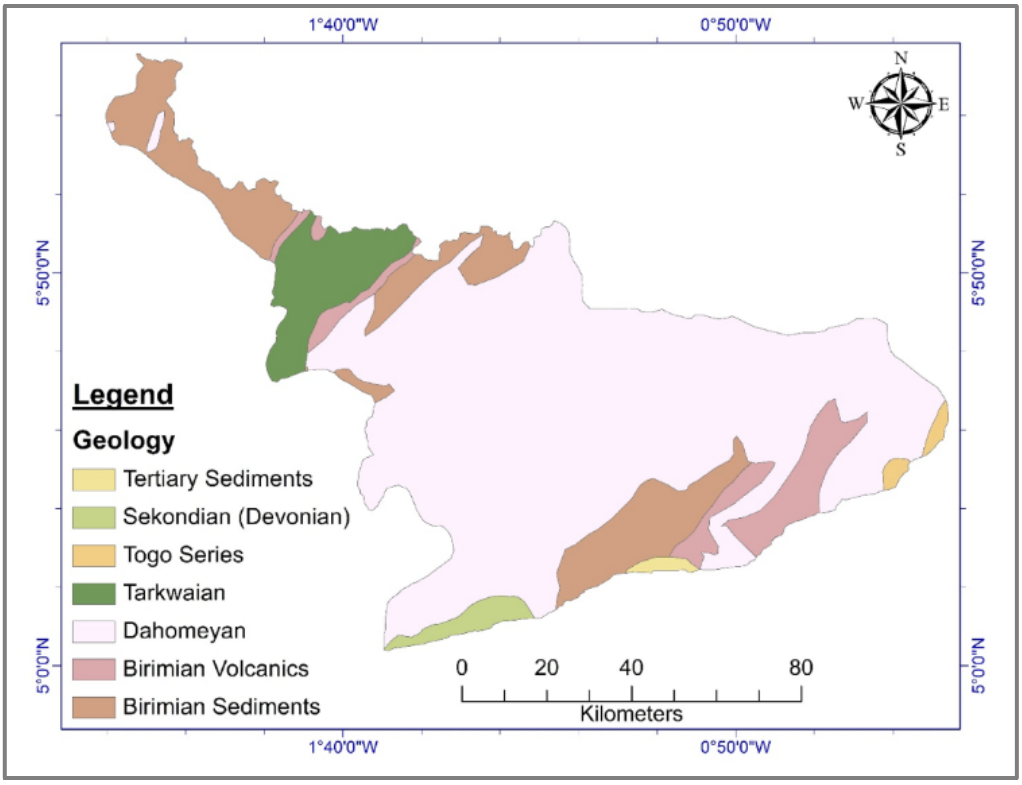

Figure 1. Geological map of Central region (Osiakwan *et al.*, 2022)

The majority of the water needs for the towns in the region are largely met by groundwater resources. This is because the reliance on transient surface water, which depends on rainfall for their replenishment, causes periodic water shortages in the settlements. Additionally, the majority of surface water bodies are so contaminated that some of them are unusable for specific purposes, so the population now relies excessively on boreholes fitted with hand pumps to supply its water demands. The development of groundwater is the most reliable source of efficient water supply in the region to accomplish the SDG targets due to the lack of reliable surface water sources. As part of the small towns water supply initiative, the Community Water and Sanitation Agency provided piped water to a few settlements in the region (CWSA, 2018).

The geology of an area determines the groundwater potential of the study area as the rocks determine the recharge rate, storativity, transmissivity, etc. (Shaban *et al.* 2006). Nearly 96% of the area is composed of Precambrian crystalline igneous and metamorphic rocks, which comprise the Upper Birimian, Lower Birimian, Tarkwaian, Togo, and Sekondian deposits. Sekondian and Tertiary deposits from the Cenozoic and Palaeozoic periods can be found along the coast. The central portion between Anomabo and Mankessim has Tertiary sedimentary strata, while the Sekondian lies west of the area (GGS, 2009). The Ashanti and Kibi-Winneba belts in the north are linked to the Upper Birimian formations, which are distinguished by lava rock types and metamorphosed tuffs, in a north-east-south-west direction. Dapaah-Siakwan and Gyau-Boakye (2000) state that isoclinal, folded, and metamorphosed schist, slate, and phyllite with interbedded greywacke comprise the Lower Birimian formation. Additionally, batholithic masses of gneisses, migmatites, and biotite granitoids intrude across the whole Birimian formation decreasing the groundwater potential. High-yielding boreholes, with an average of 12.7 m^3/hr and a range of 0.41 m^3/hr to 29.8 m^3/hr, are found in the Birimian strata, which feature considerable foliation and fractures (Dapaah-Siakwan and Gyau-Boakye 2000).

Early Proterozoic rocks from the Birimian, Kibi-Winneba, and Ashanti belts form the region's subsurface (Leube *et al.*, 1990). The Cape Coast-type biotite granites/gneisses are the primary rock type in the region. Volcaniclastics, schists, amphibolites, sandstone, conglomerate, and shale with mafic dykes are some of the additional rocks found in the region. Since the rocks in the region lack primary porosity and permeability, the hydrogeology of the region is primarily governed by secondary porosity and permeability brought about by weathering and the development of secondary structures such joints, shear zones, folds, fissures, faults, and fractures.

Method

The hydrogeochemical data for this study was obtained from the Community Water and Sanitation Agency (CWSA), Cape Coast. The CWSA provided data from a total of 136 boreholes that were sampled for physico-chemical parameters. The information was gathered as part of numerous initiatives designed to get potable water to the target populations. The samples were taken from boreholes that were situated in several Central Region recipient villages, and the locations of those boreholes were recorded using a Global Positioning System (GPS). 500 ml high-density polyethylene sampling vials were used to collect groundwater samples for in-lab testing. Most of the time, the samples were taken following a lengthy pumping period (i.e. after the pumping test). The samples must be preserved for heavy metal examination. Hence, 10 ml of 69% nitric acid were applied to the samples. While the necessary field observations and other information were being entered in the field notebook, the bottles were labelled to identify the samples.

Following the recommendations of WHO (2008) and APHA (1995), physical parameters such as pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) were measured on the field using a portable meter (Hanna equipment). The samples were taken to the Ghana Water Company Laboratory in Cape Coast for additional analysis while being maintained in an ice chest with ice packs. The groundwater samples were analyzed in the lab using the APHA (1995) recommended standards. The probe method was used to analyze the physical parameters, including TDS, EC, temperature, and pH. Ion chromatography was used to examine some of the chemical parameters, including F^-, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, PO_4^{3-}, and CO_3^{2-}, while flame atomic absorption spectrometry (AAS) was used to analyse others, including Fe, Mn, and Ca^{2+}. The formula suggested by Hem (1985) was used to convert $CaCO_3$ mg/l into HCO_3^-.

TSS was measured using photometric method 8006, TH was measured using titrimetric method, alkalinity was measured using titration method, turbidity was measured using absorptiometric method, colour was measured using cobalt standard method, salinity was measured using electrical conductivity method, whiles sodium and potassium were measured using flame photometer. Ionic balance of the samples was estimated to evaluate the quality of the laboratory data, and samples were within the range of 10% (Celesceri et al., 1998).

The factors in Table 1 were used to calculate the water quality index in this study, and by utilizing the following formula steps;

a. Assignment of weight (w_i) to the various parameters based on their perceived impact on human health.

b. Relative weight (W_i) calculation using;

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

c. Calculation of quality rating scale (qi) using;

$$q_i = 100 * \left(\frac{C_i}{S_i}\right) \quad (2)$$

d. Calculation of sub-index of each parameter SI using;

$$SI_i = W_i * q_i \quad (3)$$

e. WQI calculation using;

$$WQI = \sum SI_i \quad (4)$$

Where w_i is the assigned weight, W_i is the relative weight, n is the number of parameters, q_i is the quality rating, S_i is the WHO (2012) value in mg/l and C_i is the concentration from the laboratory in mg/l, SI is the sub-index for the various parameters and WQI is the Water Quality Index (Couillard and Lefebre, 1985).

Table 1. Groundwater quality parameters used for calculation of water quality indices

Parameter	Unit	Weight (wi)	Relative weight (Wi)	WHO (2012)
pH	pH unit	4	0.07	6.5-8.5
TH	mg/l	3	0.05	500.00
Ca^{2+}	mg/l	2	0.03	75.00
Mg^{2+}	mg/l	2	0.03	150.00
Na^{+}	mg/l	3	0.05	200.00
Cl^{-}	mg/l	4	0.07	250.00
TDS	mg/l	4	0.07	1500.00
F^{-}	mg/l	4	0.07	1.50
NO_2^{-}	mg/l	5	0.08	3.00
NO_3^{-}	mg/l	5	0.08	50.00
SO_4^{2-}	mg/l	4	0.07	250.00
Mn	mg/l	3	0.05	0.10
Fe	mg/l	3	0.05	0.30
PO_4^{3-}	mg/l	4	0.07	0.10
Turbidity	mg/l	5	0.08	5
Colour	CPU	2	0.03	15
$CaCO_3$	mg/l	2	0.03	200
TOTAL		**59**	**1.00**	

To calculate the WAQWI the following steps were taken below and parameters of Table 1;

a. Selection of water quality parameters based on their perceived impact on human health.

b. Calculation of proportionality constant (K) using;

$$K = \frac{1}{\frac{1}{\sum_{i}^{n} s_i}} \quad (5)$$

c. Calculation of quality rating (Q_i) using;

$$Q_i = \frac{C_i - V_i}{S_i - V_i} * 100 \quad (6)$$

d. Calculation of unit weight (W_i) for the nth parameter

$$W_i = \frac{K}{S_i} \quad (7)$$

e. Calculation of WAQWI

$$WAQWI = \frac{\sum W_i * Q_i}{\sum W_i} \tag{8}$$

Where K is the constant proportionality, S_i is the value of the water quality parameter obtained from the recommended standard WHO standard for drinking water, Q_i is the quality rating, C_i is the concentration of each physical or chemical parameter in each water sample in mg/l, V_i is the ideal value of the parameter in pure water ($V_i = 0$) and is considered as 7.0 for pH, W_i is the unit weight and WAQWI is the Weighted arithmetic Water Quality Index. The IRCA was calculated using the equation (García-Ubaque et al., 2018) and parameters in Table 2.

$$\%\text{IRCA} = \frac{\text{Risk score for unacceptable parameters}}{\text{Risk score for all parameters analysed}} * 100 \tag{9}$$

Table 2. IRCA's risk scores (MAVD, 2021).

Parameter	Unit	Risk score
pH	pH unit	1.5
TH	mg/l	1
Ca^{2+}	mg/l	1
Mg^{2+}	mg/l	1
Na^{+}	mg/l	1
Cl^{-}	mg/l	1
TDS	mg/l	1
F^{-}	mg/l	1
NO_2^{-}	mg/l	1
NO_3^{-}	mg/l	1
SO_4^{2-}	mg/l	1
Mn	mg/l	1
Fe	mg/l	1.5
PO_4^{3-}	mg/l	1
Turbidity	mg/l	15
Colour	CPU	6
$CaCO_3$	mg/l	1
TOTAL		**39**

Results

The statistical analysis of the groundwater data is shown in Table 3. The Table lists the several parameters that were employed in this research, along with the concentration range for each and the corresponding WHO (2012) acceptable limits. It has been noted that some samples have values that are below the acceptable limits and others have values that are above the acceptable limits.

In this study, the correlation technique was used to demonstrate the relationship that currently exists between the water quality metrics (McGrorya, 2020). This method is helpful in determining where groundwater pollution originates (Hussain, 2019). It has been effectively applied by several authors in groundwater quality research (Varol and Davraz, 2014; Agyemang 2022). The correlation outcome is shown in Table 4.

The $CaMgSO_4$, NaCl, $CaMgHCO_3$, and Mixed water types are present in the study area, according to the Piper (1944) diagram plot in Fig. 2. The majority of the samples exhibit excess Cl^- concentration above the Na^+ concentration, as shown by the plot of Na^+ vs. Cl^- in Fig. 3. By plotting the Gibb diagrams, it can be seen that rock weathering and, to a lesser extent evaporation, are the key factors influencing the chemistry of groundwater (Fig. 4 a, b). The influence of silicate weathering, carbonate weathering, and ion exchange process are displayed in the plot of CAI I vs. CAI II in Fig. 5. The study area's typical type of rock weathering process was investigated using the plot of $Ca^{2+}+Mg^{2+}$ against $SO_4^{2-}+H_2CO_3^-$, as shown in Fig 6. The diagram showed that some of the samples are above the equiline, while others are on it. The dissolution of carbonate and/or sulphate minerals is indicated by a plot of the sample on the equiline where $SO_4^{2-}+HCO_3^- = Ca^{2+}+Mg^{2+}$, the carbonate and sulphate mineral dissolution and/or ion exchange is indicated by excess $SO_4^{2-}+HCO_3^-$ over $Ca^{2+}+Mg^{2+}$, and the dissolution of silicate minerals is indicated by excess $Ca^{2+}+Mg^{2+}$ over $SO_4^{2-}+HCO_3^-$ (Tiwari and Singh, 2014). Samples that are found above the equiline (i.e., $Ca^{2+}+Mg^{2+}$ above $SO_4^{2-}+HCO_3^-$) indicate the occurrence of silicate weathering. It suggests that silicate mineral dissolution and/or ion exchange mechanisms predominate in the area.

Table 3. Statistical summary of the groundwater data

Parameter	Unit	Minimum	Maximum	Mean	Std. Deviation	WHO (2012)
pH	pH unit	4.75	9.40	6.35	0.69	6.50-8.50
Colour	CPU	1.00	188.00	9.70	16.86	15.00
EC	µS/cm	44.80	24900.00	893.81	2634.13	1000.00
TDS	mg/l	26.90	13695.00	495.38	1448.12	1500.00
TH	mg/l	6.00	9200.00	272.93	955.83	500.00
TSS	mg/l	1.00	321.00	9.52	30.73	500.00
Turbidity	mg/l	0.750	484.00	22.33	38.79	5.00
Ca hardness	mg/l	2.000	4509.00	142.27	483.30	200.00
Mg hardness	mg/l	0.005	5292.00	128.86	514.97	
Ca^{2+}	mg/l	0.800	1804.00	56.76	193.27	75.00
$CaCO_3$	mg/l	9.800	390.00	91.94	68.91	200.00
Cl^-	mg/l	3.000	8660.00	219.01	979.32	250.00
CO_3^{2-}	mg/l	0.000	32.50	0.27	2.70	
F^-	mg/l	0.001	150.00	2.65	17.60	1.50
Fe	mg/l	0.008	56.90	0.92	4.53	0.30
H_2CO_3	mg/l	0.000	476.00	110.23	84.83	
H_2PO_4	mg/l	0.001	61.70	0.88	5.02	0.10
K^+	mg/l	0.400	57.50	5.69	7.57	30.00
Mg^{2+}	mg/l	1.000	1286.00	31.20	124.77	150.00
Mn	mg/l	0.003	10.70	0.37	1.09	0.10
Na^+	mg/l	1.500	2688.00	81.53	277.76	200.00
NH_4^-	mg/l	0.001	15.00	0.13	1.23	
NO_2^-	mg/l	0.001	0.70	0.07	0.12	3.00
NO_3^-	mg/l	0.001	134.00	3.50	12.35	50.00
SO_4^{2-}	mg/l	0.001	3127.00	58.05	254.32	250.00

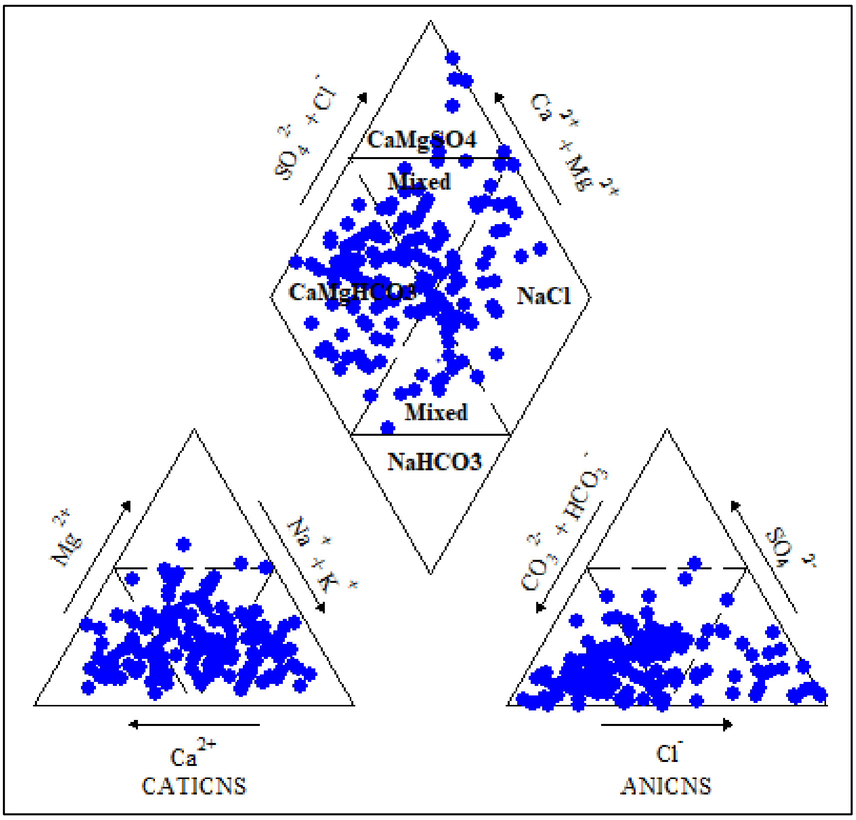

Figure 2. Piper diagram showing groundwater types in the study area.

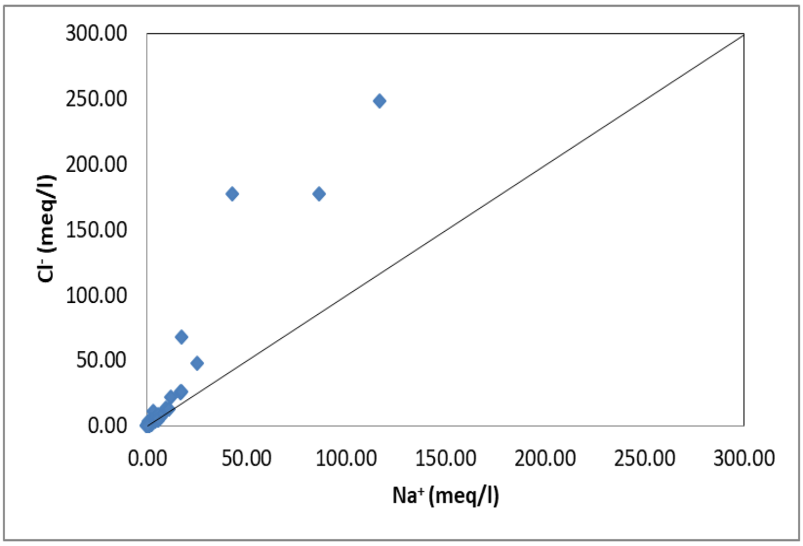

Figure 3. a plot of Cl^- vs. Na^+ concentrations

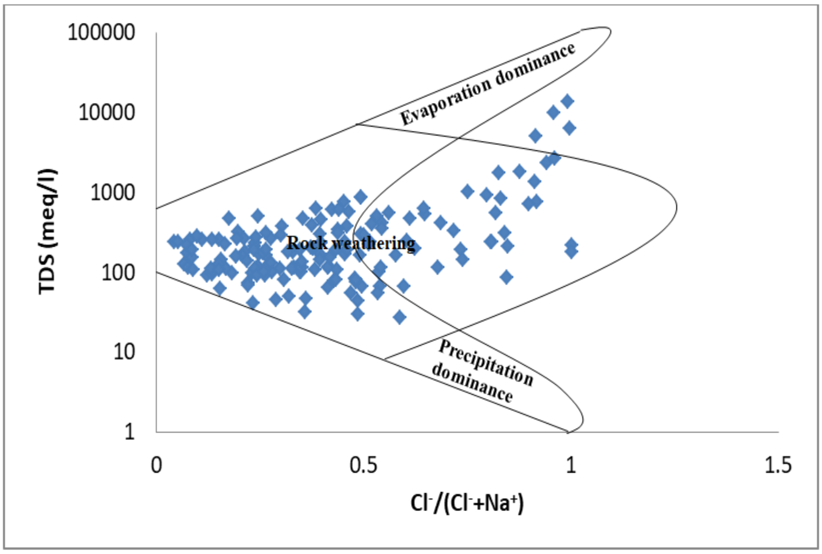

Figure 4.a A plot of TDS vs. $Cl^-/(Cl^-+Na^+)$

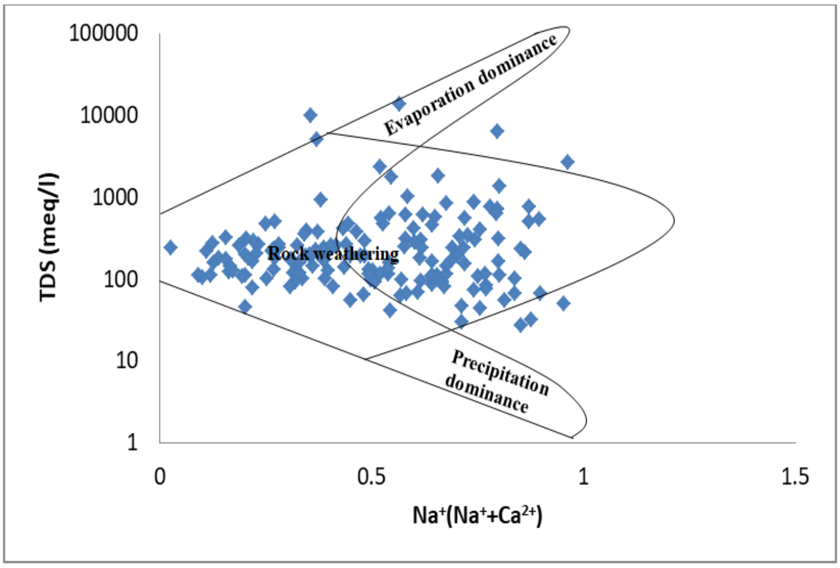

Figure 4.b A plot of TDS vs. $Na^+/(Na^++Ca^{2+})$

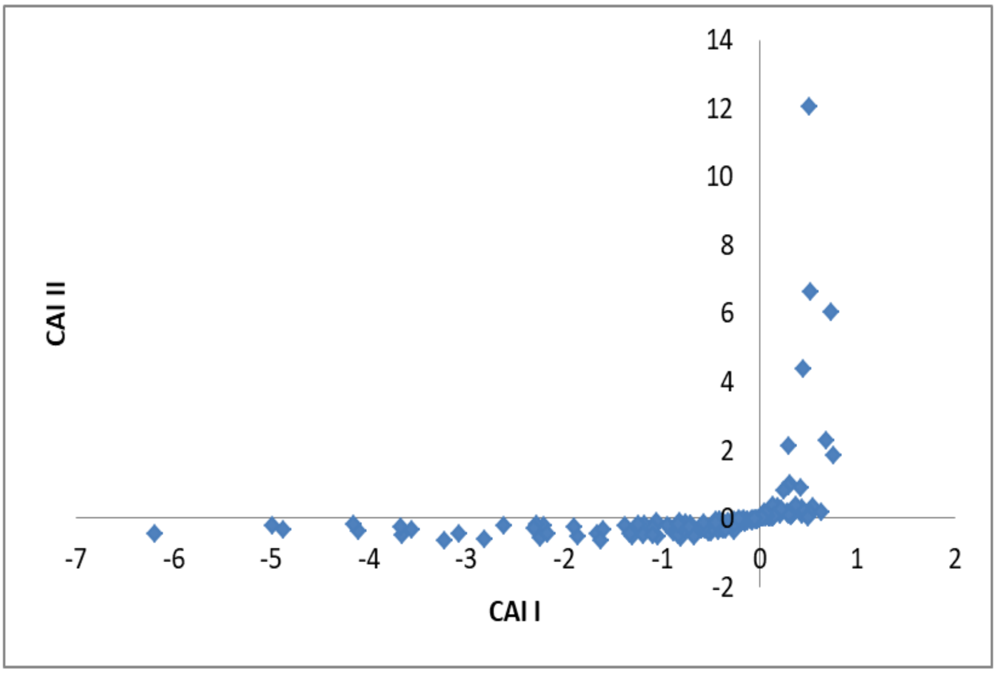

Figure 5. a plot of CAI I vs. CAI II

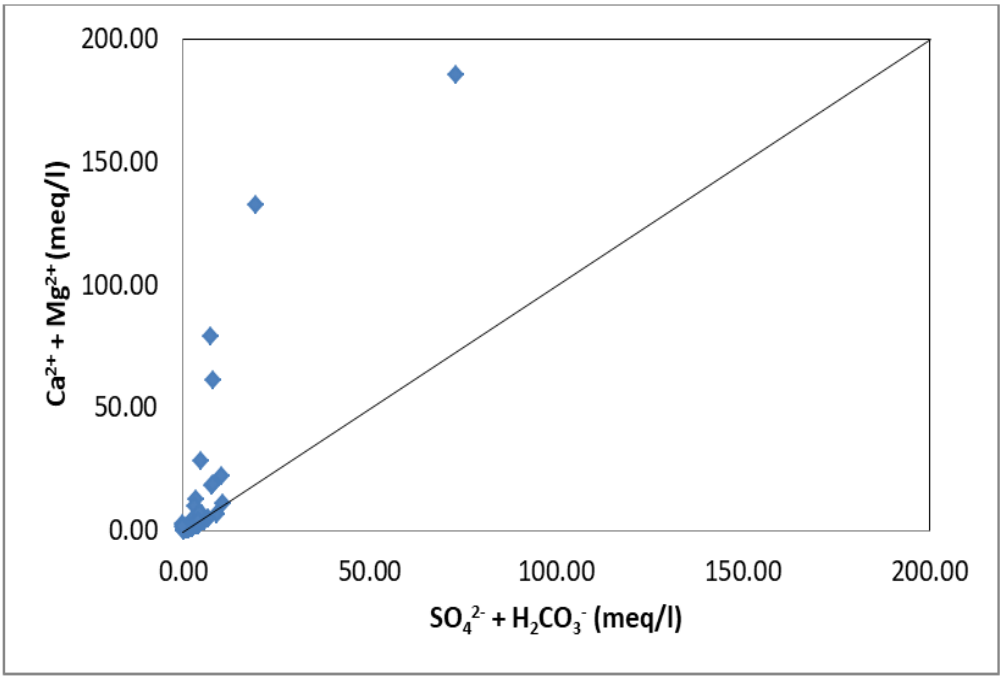

Figure 6. plot of (Ca^{2+}+Mg^{2+}) vs. (SO_4^{2-}+$H_2CO_3^-$)

The classification of the computed WQI, WAQWI, and IRCA values for the groundwater samples are shown in Table 5. To show the spatial variation of the various classes of water quality indices, codes of 1-5 were assigned to the classes as shown in Table 5. The spatial distribution maps of the indices are shown in Figures 7, 8, and 9. Additionally, Fig. 10 illustrates how the WQI, WAQWI, and IRCA tools broke down the major groups. To show the spatial distribution of the WQI, WAQWI, and IRCA values, numerical weight were assigned to the various classes as codes as shown in Table 5.

Table 4. Correlation Table of physicochemical parameters

	Turb.	**Col.**	**pH**	**EC**	**TSS**	**TDS**	**Na**	**K**	**Ca**	**Mg**	**Fe**	**NH_4**	**Cl**	**SO_4**	**PO_4**	**Mn**	**NO_2**	**NO_3**	**TH**	**$CaCO_3$**	**Ca_hard.**	**Mg_hard.**	**F**	**H_2CO_3**	**CO_3**
Turb.	1.00	**0.85**	0.14	0.01	0.08	0.01	0.00	-0.03	-0.01	0.00	**0.91**	0.01	0.00	0.01	0.00	0.47	0.08	-0.03	0.00	-0.03	0.00	0.00	-0.02	-0.04	0.08
Col.		1.00	0.13	-0.01	0.20	-0.01	-0.02	0.01	-0.03	-0.01	**0.84**	-0.04	-0.03	-0.01	-0.04	0.44	0.03	-0.06	-0.02	0.04	-0.02	-0.02	-0.04	0.04	0.06
pH			1.00	0.03	-0.15	0.03	0.03	0.11	0.04	0.02	0.12	0.17	0.01	0.03	0.13	0.16	0.11	0.08	0.03	0.32	0.04	0.02	0.12	0.27	0.42
EC				1.00	-0.05	1.00	**0.93**	**0.53**	**0.97**	**0.86**	-0.01	-0.02	**0.98**	**0.72**	-0.03	0.03	-0.05	0.01	**0.95**	0.32	**0.97**	**0.86**	0.06	0.33	-0.03
TSS					1.00	-0.05	-0.03	-0.02	-0.05	-0.03	0.03	-0.03	-0.03	-0.03	-0.03	-0.02	-0.06	0.02	-0.04	-0.10	-0.05	-0.03	-0.04	-0.09	-0.02
TDS						1.00	**0.93**	**0.52**	**0.97**	**0.86**	-0.01	-0.02	**0.98**	**0.72**	-0.03	0.03	-0.05	0.01	**0.95**	0.32	**0.97**	**0.86**	0.06	0.33	-0.03
Na							1.00	**0.59**	**0.83**	**0.74**	0.00	-0.03	**0.96**	**0.51**	-0.03	0.04	-0.06	0.01	**0.82**	0.18	**0.83**	**0.74**	0.07	0.18	-0.02
K								1.00	0.45	0.37	0.00	-0.01	**0.52**	0.24	-0.01	0.02	-0.06	0.03	0.42	0.38	0.44	0.37	0.12	0.38	-0.04
Ca									1.00	**0.84**	-0.01	-0.01	**0.92**	**0.80**	-0.02	0.03	-0.06	0.01	**0.96**	0.36	**1.00**	**0.84**	-0.01	0.37	-0.03
Mg										1.00	-0.02	-0.02	**0.87**	**0.89**	-0.03	0.04	-0.08	0.01	**0.96**	0.37	**0.84**	1.00	0.10	0.37	-0.02
Fe											1.00	0.00	-0.02	0.00	0.00	**0.52**	0.04	-0.01	-0.02	0.01	-0.01	-0.02	-0.01	0.02	-0.01
NH_4												1.00	-0.02	-0.02	**0.58**	-0.04	**0.53**	**0.93**	-0.02	0.02	-0.03	-0.03	**0.74**	-0.13	-0.01
Cl													1.00	**0.69**	-0.03	0.03	-0.07	0.01	**0.93**	0.23	**0.92**	**0.87**	0.06	0.24	-0.02
SO_4														1.00	-0.03	-0.01	-0.05	-0.01	**0.88**	0.39	**0.80**	**0.89**	0.00	0.39	-0.02
PO_4															1.00	-0.03	0.48	**0.66**	-0.03	-0.02	-0.03	-0.03	**0.56**	-0.13	-0.01
Mn																1.00	-0.02	-0.05	0.03	0.22	0.03	0.04	-0.05	0.23	-0.03
NO_2																	1.00	**0.54**	-0.07	-0.07	-0.07	-0.08	0.41	-0.15	0.00
NO_3																		1.00	0.01	0.00	-0.01	0.01	**0.72**	-0.14	-0.02
TH																			1.00	0.39	**0.96**	**0.96**	0.05	0.39	-0.03
$CaCO_3$																				1.00	0.37	0.37	0.02	**0.99**	-0.07
Ca_hard.																					1.00	**0.84**	-0.03	0.37	-0.03
Mg_hard.																						1.00	0.10	0.37	-0.02
F																							1.00	-0.10	-0.01
H_2CO_3																								1.00	-0.12
CO_3																									1.00

Bolded values showed significant correlations

Table 5. WQI, WAQWI and IRCA classifications (Couillard & Lefebre, 1985; Tygai, 2013; MAVD, 2021)

Classification	Assigned code	WQI	WAQWI	IRCA
Excellent	0.1-1.0	0-50	0-25	0-5
Good	1.1-2.0	50-100	25.1-50	5.1-14
Poor	2.1-3.0	100-200	50.1-75	14.1-35
Very Poor	3.1-4.0	200-300	75.1-100	35.1-80
Unsuitable	4.1-5.0	>300	>100	80.1-100

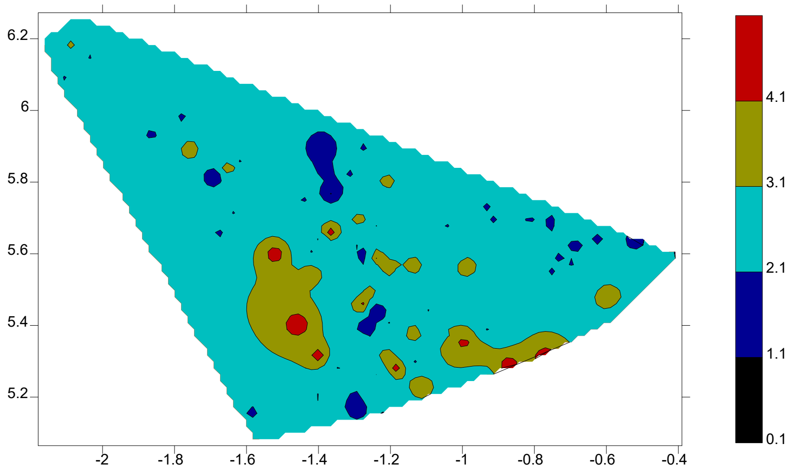

Figure 7. Spatial distribution of WQI

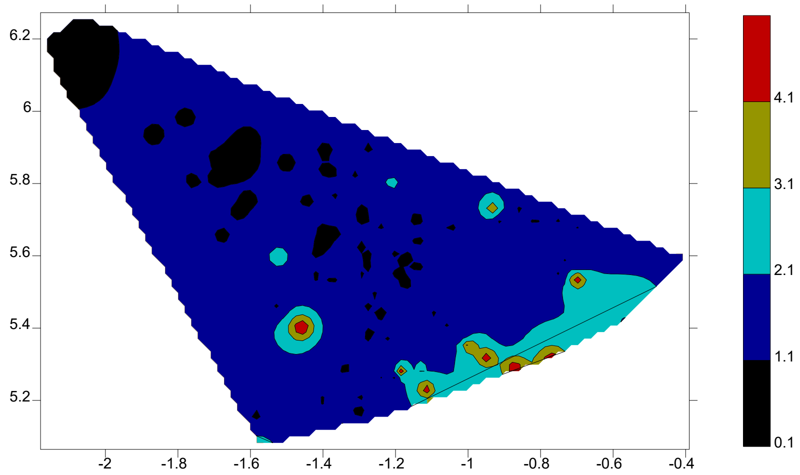

Figure 8. Spatial distribution of WAQWI

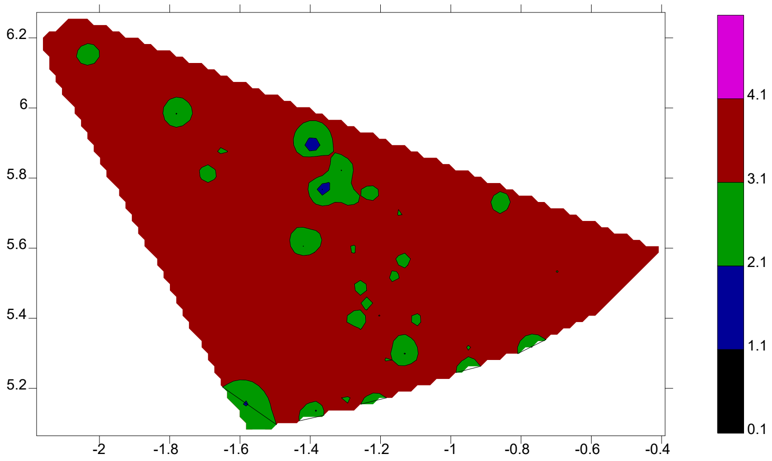

Figure 9. Spatial distribution of IRCA

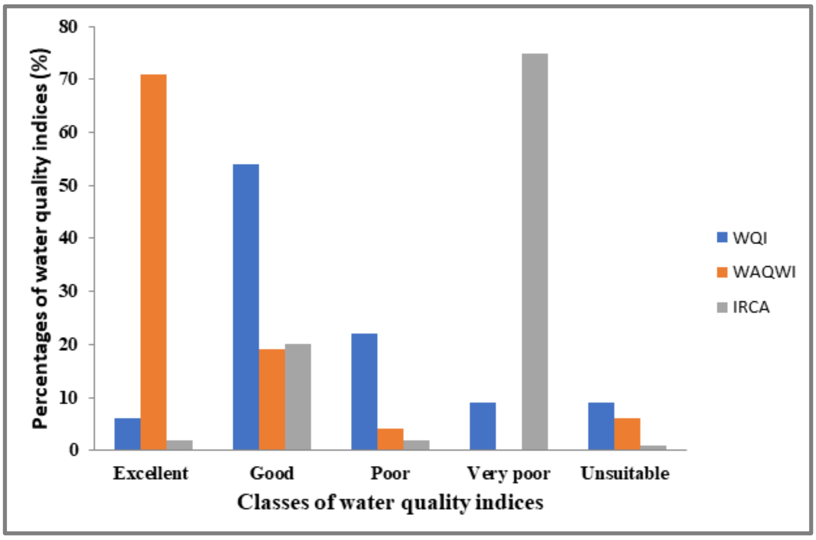

Figure 10. Classification of the water quality indices and IRCA

Discussion

The average pH of the groundwater is 6.351 pH units, with a range of 4.750 pH units to 9.400 pH units. This demonstrates that certain samples have pH levels that are either below or over the 6.5–8.5 limits for drinking water recommended by the WHO (2012). This indicates that some of the samples are basic and some are acidic, making them unfit for drinking without treatment. TDS has a range of 26.900 to 13695.000 mg/l with a mean of 495.378 mg/l. While some of the samples are below the 1500 mg/l drinking water recommendation, several are far above the limit. The mean EC value for the groundwater samples is 893.812 S/cm, with a range of 44.800 S/cm to 24900.000 S/cm. This indicates that a few of the samples are greater than the suggested value of 1000 S/cm. The range of TH was 6.000-9200.000 mg/l with a mean of 272.930 mg/l indicating that some of the samples have higher TH values than the recommended value of 500 mg/l.

TSS has a range of 1.000 mg/l to 321.000 mg/l. with an average of 9.520 mg/l. This demonstrates that all of the samples have readings below the suggested level of 500 mg/l. Turbidity ranges from 0.750 to 484.000 mg/l, with a mean of 22.330 mg/l. This demonstrates that some of the samples have readings that are higher than the advised level of 5 mg/l. With a mean of 9.701 CPU, the samples' color runs from 1.000 CPU to 188.000 CPU. This indicates that some of the samples have color values over the suggested level of 15 CPU. It is apparent that the groundwater's physical properties have quite large changes when considered their concentration. This observation may be explained by the various geographic locations of the borehole samples used in the study inside the recharge zone or discharge zone of the aquifer systems.

Potassium has a concentration range of 0.400–57.500 mg/l, with a mean of 5.686 mg/l. Some of the samples show readings that are higher than the safe drinking water standard of 30 mg/l. Na^+ has an average concentration of 81.532 mg/l with a range of 1.500 mg/l to 2688 000 mg/l. This indicates that a few samples contain concentrations that are extremely high compared to the suggested value of 200 mg/l. Ca^{2+} ranges from 0.800 to 1804.000 mg/l with a mean of 56.763 mg/l, indicating that certain sample values are higher than the recommended value of 75 mg/l. With a mean of 31.202 mg/l, Mg^{2+} has a range of 1.000 mg/l to 1286.000 mg/l. This indicates that a few samples contain high concentrations that are over the recommended level of 150 mg/l. With a mean of 0.372 mg/l, the Mn content ranges from 0.003 mg/l to 10.700 mg/l. This demonstrates that some samples have levels higher than the 0.10 mg/l threshold for drinking water.

With a range of 0.008 mg/l to 56.900 mg/l and a mean of 0.918 mg/l, the Fe content indicates that some samples may have values higher than the advised threshold of 0.30 mg/l. The range of Cl^- concentrations, from 3.000 mg/l to 8660.000 mg/l, with a mean of 219.009 mg/l, suggests that some samples have values higher than the recommended value of 250 mg/l. The CO_3^{2-} range has a mean of 0.271 mg/l and a range of 0-32.500 mg/l. $H_2CO_3^-$ concentrations range from 0 to 476.000 mg/l, with a mean of 110.226 mg/l. The average NH_4^- content is 0.131 mg/l, however it ranges from 0.001 mg/l to

15.000 mg/l. The range of NO_2^- concentration is 0.001-0.700 mg/l, and the mean value is 0.065 mg/l, which means that some samples had levels higher than the recommended amount of 3 mg/l. The range of NO_3^- is 0.001-134.000 mg/l, and the mean value is 3.504 mg/l, indicating that some samples have NO_3^- concentrations that are higher than the advised value of 50 mg/l. With a mean concentration of 58.046 mg/l, the range of SO_4^{2-} is 0.001-3127.000 mg/l. This demonstrates that some samples have values that are higher than the suggested level of 250 mg/l. PO_4 concentrations range from 0.001-61.700 mg/l, with a mean of 0.878 mg/l. This indicates that some of the samples had readings that are higher than the advised level of 0.10 mg/l. F^- concentrations range from 0.001 to 15 000 mg/l, with a mean of 2.647 mg/l. This demonstrates that some samples have results over the suggested level of 1.5 mg/l.

Similar to the physical characteristics, the spatial distribution of the sampled boreholes for this study may also be responsible for the large fluctuations in the cations and anion concentrations within the groundwater. Groundwater cation and anion concentration variations may be caused by a variety of factors, including rock weathering, ion exchange, precipitation, evaporation, and impacts of anthropogenic activities. According to the study, the groundwater types in the area include Ca-Mg-SO_4, Na-Cl, Ca-Mg-HCO_3, and mixed water types and the processes that control the groundwater chemistry include silicate weathering, carbonate weathering, ion exchange, and the potential effects of anthropogenic activities like improper waste disposal, the use of pit latrines, open defecation, mining, and galamsey activities. To examine the impact of ion exchange on groundwater chemistry, a plot of CAI I vs. CAI II was employed. According to Schoeller (1965), CAI I and CAI II positive values indicate that Na^+ or K^+ in groundwater exchanges with Mg^{2+} or Ca^{2+} in the aquifer system, and negative values indicate that Mg^{2+} or Ca^{2+} in groundwater exchanges with Na^+ and K^+ in the rocks. Positive numbers indicate ion exchange, while negative values indicate reverse ion exchange. Reverse ion exchange predominat the groundwater from the study area.

Correlation Analysis

The use of the correlation analysis technique revealed a substantial association between turbidity, Fe, and colour, suggesting that the content of Fe in the groundwater regulates turbidity. Strong correlations between colour and Fe imply that the groundwater's Fe concentration affects the color. The EC is correlated with Mg^{2+} hardness, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, and Ca^{2+} hardness, indicating that the amounts of these substances affect the groundwater's EC. As shown by the factor analysis and cluster analysis approaches, geogenic processes and human activities may be in control of the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} in the groundwater. As a result, these factors affect the EC of the groundwater. The fact that TDS closely correlates with Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, Ca hardness, and Mg hardness suggests that the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} in the groundwater affect the TDS of the groundwater. This indicates that anthropogenic activities as well as rock weathering affect the TDS.

The correlations among cations and anions reflect the effect of weathering of the source rocks. The relationship between K^+ and Cl^- shows that anthropogenic activities have an impact on the chemistry of groundwater and the overall quality of groundwater. The relationship between Ca^{2+} and Cl^-, SO_4^{2-}, Mg^{2+}, TH, Ca^{2+} hardness, and Mg^{2+} hardness suggests that the weathering of rocks has an effect on the quality of the groundwater. Mg correlates with Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness, illustrating how the weathering of rocks affects the quality of groundwater. Fe and Mn are correlated, which shows that weathering of rocks has an effect of the groundwater chemistry. The relationship between NH_4^+ and F^-, NO_2, NO_3, and PO_4 indicates that anthropogenic activities, such as applying fertilizer to farmland, poor hygienic conditions around boreholes, using chemicals for galamsey activities, using pit latrines, etc., have an impact on the chemistry and general quality of groundwater.

The relationship between Cl^- and SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness suggests that anthropogenic activities have an impact on groundwater quality. The correlation between SO_4^{2-} and TH, Ca^{2+} hardness and Mg^{2+} hardness suggests that SO_4^{2-} may have an impact on groundwater hardness. PO_4 correlates with NO_3 and F^-, demonstrating how human activities affect the quality of groundwater. The relationship between NO_2 and NO_3 implies that the conversion of NO_3 to NO_2 is the primary factor affecting the content of NO_2 in groundwater. NO_3 correlates with F-, demonstrating that anthropogenic sources account for the majority of the NO_2 entering the groundwater system. A portion of the concentration is changed into NO_2 upon the introduction of NO_3. The use of the correlation analysis technique confirms the potential impact of ion exchange, rock weathering, and human activity on the region's groundwater chemistry and general quality. The various associations point to the potential effects of mineral dissolution and human activities including improper waste disposal, a lack of hygienic conditions around boreholes, and the use of fertilizers on agricultural land on the chemistry of groundwater (Driscoll et al., 1989; Koh et al., 2010; Tiwari and Singh, 2014).

Water quality index (WQI)

The WQI scores are divided into five groups based on various ratings. When the value falls between 0 and 50, it is considered to be water of excellent quality for drinking, between 50 and 100, it is considered to be good for drinking, between 100 and 200, it is considered to be water of poor quality for drinking, between 200 and 300, it is considered as water of very poor quality and above 300, it is considered to be water of unsuitable quality (Couillard and Lefebre, 1985). The WQI determined that 6% of the groundwater samples had excellent quality, 54% had good quality, 22% had poor quality, 9% had very poor quality, and 9% were unfit for drinking purposes based on this classification. By making a thematic map, the spatial distribution of the WQI is displayed. The majority of the water quality readings fall between 50% and 100%. Poor and very poor water types can be found in coastal areas and some central regions. This observation might be explained by the interactions between groundwater and seawater near the coastline areas of the region. The low groundwater quality along the coast may be caused by a potential seawater intrusion. However, the occurrence of poor, extremely poor, and unsuitable water types in the region's central part may be attributed to the effects of anthropogenic activities. The majority of the locals are farmers, and they treat the farmland with various pesticides and animal dung. Once more, sloppy small-scale mining operations are widespread in the Region, and this may also be the reason for the area's documented groundwater quality issues.

Weighted arithmetic Water Quality Index (WAQWI)

When there are no contaminants in the water, the quality rating in the WAQWI calculation is zero, and it is 100% when the parameter has the recommended value of the WHO (2012). However, as contamination levels increases, the quality rating's worth decreases. Garcia-Avila et al. (2018) claim that a water quality parameter's relative weight is inversely related to the WHO's suggested values. The final WAQWI scores are divided into five categories with varying ratings. When the value is between 0 and 25, it is graded as A, meaning the water is excellent for drinking. When the value is between 26 and 50, it is graded as B, meaning the water is good for drinking. When the value is between 51 and 75, it is graded as grade C, meaning the water is poor. When the value is between 76 and 100, it is graded as D, meaning the water is very poor. When the value is above 100, it is graded as grade E, meaning the water is unsuitable for drinking without treatment (Tygai, 2013). According to the study, 71% of the groundwater in the study region is of grade A water type, followed by 19% grade B, 4% grade C, 0% grade D, and 6% grade E. This implies that the groundwater in the research area is generally suitable for human consumption. However, since the quality varies by location, it is necessary to test the water before consuming it. In some areas, the water is of poor quality.

IRCA determination

The IRCA, which has a value range of zero to one hundred, is one of the water quality indices used to evaluate the quality of drinking water. Like all water quality indices, it breaks down complex data on drinking water samples' water quality into a number that can be easily understood by various professional groups. The index makes use of variables whose potential effects on human health have been given a risk score. Depending on the range that the IRCA values fall into, they are divided into five groups. The value is considered to pose no risk to human health when it falls within the range of 0 to 5, low risk when it falls within the range of 5.1 to 14, medium risk when it falls within the range of 14.1 to 35, high risk when it falls within the range of 35.1 to 80, and sanitarily infeasible when it falls within the range of 80.1 to 100 (MAVD, 2021). In Table 2, the parameters that were utilized to calculate the IRCA are listed along with the corresponding risk score.

According to the IRCA calculations, 2% of the samples contain water that poses no risk to human health, 20% contain water that is low risk, 2% contain water that is medium risk, 75% contain water that is high risk, and 1% contains water of unsuitable quality for drinking. This indicates that the bulk of the samples have high-risk potential for human consumption and that the groundwater is not appropriate for drinking without prior treatment. The observation is related to the majority of the samples' generally low pH values and high observed values of turbidity, color, Mn, Fe, and PO_4 in comparison to WHO (2012) recommended values.

The weights assigned to the various water quality parameters are based on their potential effects on human health, similar to other water quality indices. High potential parameters are given higher weights, whilst low potential parameters are given lower weights. The monitoring of water quality in Colombia from 2008 to 2012, according to Garca-Ubaque et al. (2018), showed that the calculated IRCA value was around 13.4%, which denotes water of a low-risk level. Since the water sources in Sincern and Gambote municipalities provide a significant risk to human health, Duarte-Jaramillo et al. (2021) investigated them and concluded that the sources should not be used for drinking. The domestic water supply network in Azogues, Ecuador, was evaluated by Garcia-Avilla et al. (2022), who found that the samples exhibited IRCA levels between 0 and 5%. As a result, the water that was being provided was deemed safe for consumption and assigned the water type designation "No-risk."

Comparison of the WQI, WAQWI and IRCA

The Water action decade (2018–2028) was established by the UN general assembly in response to a trend that raises the possibility of an impending global water catastrophe (UNDESA, 2014; 2021). Achieving universal access to clean water and sanitary facilities is a specific goal of Sustainable Development Goal (SDG) 6. According to research, there are two billion people without access to clean drinking water worldwide (UNDESA, 2021). Studies in a few African nations have shown that some of them are already dealing with water issues (Sachs et al., 2021). According to the survey, roughly eight countries rely on less than 50% of the minimum facilities they need for drinking water, while over fifteen countries rely on less than 60% of the necessities (SDG Index, 2021).

The spread of galamsey activities in Ghana has had a significant negative impact on the environment and water resources. Most of the water bodies that formerly provided an alternative source of water for the population have become so polluted as a result that some of them are no longer suitable for certain purposes. As a result, there is now less water available and there are problems with the water's quality. According to the WQI, 6% of the groundwater samples had excellent quality, 52% had good quality, 34% had poor quality, 3% had very poor quality, and 5% were unfit for drinking purposes. According to the WAQWI, 71% of groundwater samples are grade A, followed by 19% grade B, 4% grade C, 0.00% grade D, and 6% grade E. According to the IRCA calculations, 2% of the samples contain water that poses no risk to human health, 20% contain water that is low risk, 2% contain water that is medium risk, 75% contain water that is high risk, and 1% contains water that is unfit for human consumption.

According to this observation, approximately 58% of groundwater samples based on WQI, 90% based on WAQWI, and just 22% based on IRCA are suitable for human consumption. This discovery demonstrates that while the two water quality indexes differ greatly from the IRCA, they do share some characteristics. The findings of the study by Osiakwan et al. (2021), which applied the entropy-based groundwater quality index (IEBGWQIs) for the assessment of groundwater quality for drinking purposes in the Central Region of Ghana, are consistent with the results of the two water quality indices. According to their research, the groundwater quality of the samples taken was evaluated to be excellent, good, average/medium, poor, or extremely poor in 59.4%, 20.3%, 7.8%, 2.6%, and 9.9% of the groundwater samples, respectively.

Additionally, as observed in the spatial distribution maps of the two indices employed in this study, the areas around the coast have very poor groundwater quality while the northern part has outstanding groundwater quality. The bulk of the groundwater samples fall within the excellent category, according to the results from the WAQWI. As a result, consuming the groundwater is generally safe. In their investigations, Agarwal et al. (2020) used WAWQI and CCME WQI methodologies to examine the water quality in India and found that, respectively, 82% and 77% of the samples had poor to inappropriate water types. The observations between the two water quality indicators did not differ significantly, as the current study has shown.

It is important to note that the groundwater samples are untreated raw samples. The fact that some of the samples had poor to unacceptable quality for drinking is therefore not surprising. This explains why the IRCA technique which is often used to evaluate the quality of drinking supply water that may have undergone some type of treatment indicated the extremely poor quality of groundwater. According to the study, in order to protect the public's health, the groundwater in the studied region needs to be treated before being utilized for drinking purpose. The Region has a total population of approximately 2859821 and a land area of approximately 9826 km^2 (GSS, 2021). For their water needs, the majority rely on groundwater supplies. The rural communities are more susceptible to water-related public health problems due to the potential of contaminated groundwater and often lack of treatment before drinking.

Conclusion

In the Central Region of Ghana, a comparative research of groundwater quality has been conducted utilizing two groundwater risk indices and two water quality indices. The area's groundwater types include $CaMgSO_4$, NaCl, $CaMgHCO_3$, $NaHCO_3$, and Mixed water types. Silicate weathering, carbonate weathering, ion exchange, and potential anthropogenic activity effects, such as poor hygiene around boreholes, the use of agrochemicals on farmlands, improper waste disposal, the use of pit latrines, open defecation, mining, and galamsey activities, control the groundwater chemistry. According to the WQI, 6% of the groundwater samples had excellent quality, 54% had good quality, 22% had poor quality, 9% had very poor quality, and 9% were unfit for drinking without treatment. According to the WAQWI, 71% of groundwater samples are of outstanding quality, followed by 19% of acceptable quality, 4% of bad quality, and 6% of unsuitable quality. IRCA calculations showed that 2% of the samples included water that posed no risk to human health, 20% contained water that was low risk, 2% contained water that was medium risk, 75% contained water that was high risk, and 1% contained water that was unfit for human consumption.

The WQI and WAQWI water quality indices display a comparable pattern. However, the IRCA in the study area has a different pattern. The IRCA indicates that there is a generally high level of health risk associated with using the groundwater for drinking without prior treatment, despite the fact that the two indices indicate that the groundwater is generally good for that purpose. The observation is related to the majority of the samples' generally low pH values and high observed values of turbidity, color, Mn, Fe, and PO_4 in comparison to WHO (2012) recommended values. The study has demonstrated the value of WQI, WAWQI, and IRCA as instruments for evaluating and comprehending groundwater quality for drinking purpose. Particularly, in developing nations like Ghana, their use is helpful in achieving the SDG 6.

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Compliance with Ethical Standards

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