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Groundwater quality assessment for sustainable irrigation in Nanton district, Ghana

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ABSTRACT

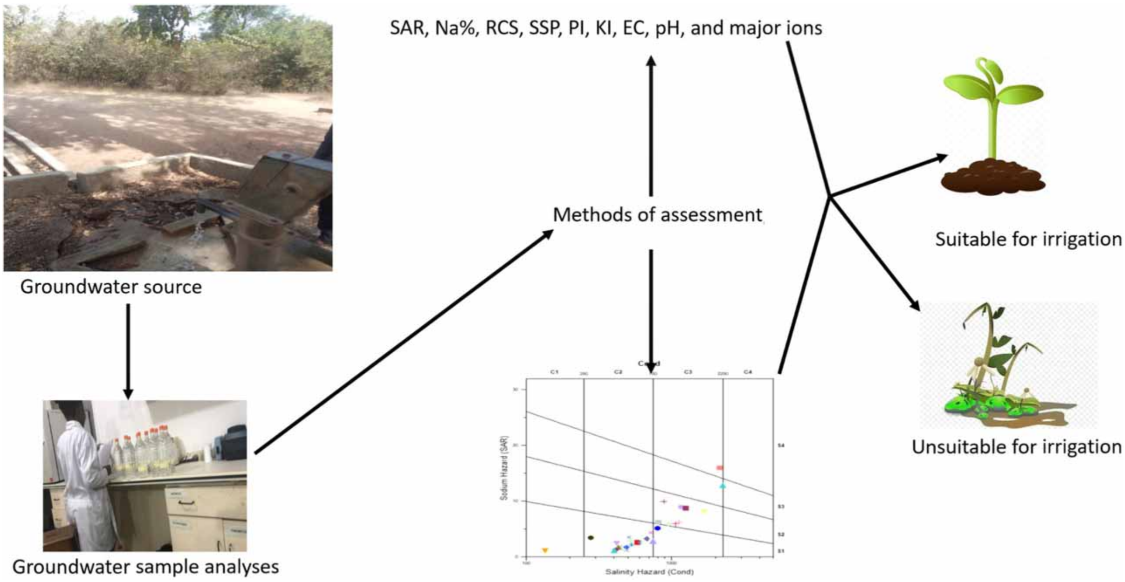
As part of the semi-arid region, Ghana falls within the West African Sahel region with high climatic variability and severe droughts, especially in the Northern parts. The Northern region is characterized as one of the driest in Ghana. It experiences one rainy season in a year, though agriculture is one of the main economic activities. Nanton district in the Northern region consists of farming communities. However, there is limited availability of water for crop watering during the dry season and groundwater could become a possible source of water supply. This research, therefore, seeks to provide information on the irrigation quality status of groundwater in the Nanton district. Information from this research also aims to assist policymakers take the right decisions for sustainable agriculture in the study area. Irrigation water indexes in combination with the USSL diagram were adopted as methods for analyses in this research. Results generally suggest that groundwater in the study area is suitable for irrigation purposes, except for a few places in the district. Further studies should be conducted to precisely state the quality of water used for drinking and domestic purposes. The research should also emphasize identifying factors controlling groundwater chemistry in the area.

Key words: irrigation water indexes, Nanton, sustainable irrigation, USSL diagram

HIGHLIGHTS

- This paper presents preliminary insights into groundwater as a sustainable alternative source for agriculture.
- Stakeholders can utilize the information in this study to enhance farming activities within the area.
- Policymakers can make informed decisions toward achieving food security based on the findings of this research.
- The findings support irrigation as a contributing factor toward the improvement of agribusiness.
- The research supports Nanton's socio-economic growth through efficient and responsible use of groundwater.

GRAPHICAL ABSTRACT



1. INTRODUCTION

There have been significant changes in the use of land for various purposes due to economic development and rapid population growth. This has resulted in the excessive exploitation of water resources for various civil, industrial, and agricultural activities. Also, the problems of climate change and its impact on socioeconomic development in communities are felt globally. This phenomenon has increased the demand for water resource exploration for use in sustainable agricultural activities, especially in the arid and semi-arid regions including Ghana. As part of the semi-arid regions, Ghana falls within the West Africa Sahel region with high climatic variability and severe droughts, especially in the Northern, Upper East, Upper West, Northeast, and Savanna regions.

The Northern region is characterized as one of the driest in Ghana due to its proximity to the Sahara Desert and experiences one rainy season though agriculture is one of the main economic activities in the region. Also, recent changes in climatic conditions have affected rainfall patterns in the region causing a significant decrease in crop yield as well as other agricultural productions. These have resulted in an increased demand for water resources exploration in communities in Nanton district within the region, for sustainable agricultural activities.

The Nanton district entirely consists of farming communities due to the availability of fertile land as reported by the District Planning Coordinating Unit (2021). The availability of fertile land in these areas has resulted in unplanned ruralization, putting pressure on water resources. The major source of water for agricultural activities in these areas is seasonal rainfall. The few dug-outs available for irrigation purposes dry out completely during the dry season. As a result of this, farmers in the area need additional sources such as groundwater supply for irrigation purposes during the dry season. The district has the potential of increasing food production in the region as well as in Ghana, due to the availability of fertile land for good crop yields. However, an adequate constant supply of water to support crop production in the area during the dry season is a challenge for farmers. Therefore, an alternative such as groundwater could become a source for crop watering in the area during the dry season. However, the irrigation quality status of groundwater in the area is unknown. As a result, it is significant to provide the necessary information needed for groundwater in the area for use in irrigation purposes.

In this 21st century, modern techniques have been used to assess and manage groundwater for irrigation purposes (Al-Saffawi *et al.* 2020). Some of these methods included irrigation water indexes like sodium adsorption ratio (SAR), percentage sodium (Na%), residual sodium carbonate (RSC), soluble sodium percentage (SSP), permeability index (PI), Kelly index (KI), and United States Salinity Laboratory (USSL) diagram or conductivity sodium hazards (CS) plot. According to Al-Saffawi *et al.* (2020), these methods are the most significant means of assessing the pollution and suitability of water for irrigation purposes. Notably, the USSL diagram utilizes chemical parameters such as electrical conductivity (EC) and SAR to assess the quality of water for irrigation, while the irrigation water indexes use a combination of several parameters such as Cl^-, CO_3^{2-}, HCO_3^-, Mg^{2+},

Ca^{2+}, K^+, and Na^+ in the assessment. Given these, the study has adopted the methods to assess the quality of groundwater in the Nanton district of Ghana for irrigation purposes.

2. MATERIALS AND METHODS

2.1. Description of the study area

The research area is in the center of Northern Ghana. To the west, it shares boundaries with the Savelugu Municipality, Sagnarigu Municipality to the southwest, and Tamale Metropolis to the south. The Nanton district shares boundaries with the Karaga district to the east and the Mion district in the south-eastern part (N. District Planning Coordinating Unit 2021).

2.2. Geology, topography, and drainage

Extensive sedimentary rock formation characterizes the geology of the study area. These sedimentary rocks consist of the Oti and Obosom sedimentary rocks (Ampofo *et al.* 2018). The southern part of the district is covered by the Obosom group of sedimentary rocks and consists of uniform siltstone, shale, and mudstone (Ampofo *et al.* 2018).

The landscape of the district is mainly flat and low-lying with an average height of 300 m above sea level (N. District Planning Coordinating Unit 2021). The land in the district is covered by sandy loamy, gravel deposits, and clay soil types. The district has poor drainage systems due to the unavailability of major rivers except for a few dams. In a report cited by the District Planning Coordinating Unit (2021), all dams and ponds in the district get dried up during the dry season, leaving the district with no surface water.

2.3. Sample collection

Thirty (30) groundwater samples (twenty-nine (29) boreholes and one (1) open well) were collected at 30 different locations from December 2022 to January 2023 in the study area during the dry season, when groundwater level is expected to be running low. This was done to obtain a representative sample from the groundwater aquifer matrix. The samples were collected in a 1-L capacity preconditioned polyethylene bottle. Before sampling, each sample bottle was rinsed thoroughly with the water to be sampled. Global Positioning System (GPS) coordinates Android version 1.17 was used to establish sampling points. The sample's location map is presented in Figure 1. Groundwater sampling protocols described by Barcelona *et al.* (1985) were adopted in this study (Table 1).

2.4. Laboratory analysis of samples

Parameters such as pH and EC were determined by Multimeter OAKTON PC 450. Sodium (Na^+) was analyzed by Jenway PFP7 flame photometer, while magnesium (Mg^{2+}) and calcium (Ca^{2+}) were analyzed by the classical EDTA titrimetric method. Chloride (Cl^-) was analyzed by an argentometric method using potassium dichromate K_2CrO_7 as an indicator. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were also determined by the titration method. Standard analytical procedures described by APHA (2012) were followed in all the analyses. The accuracy of groundwater sample analysis in the laboratory at each sampling point was determined using the ionic balance equation reported by APHA (2012). All samples were within the 5% ionic balance limit for the analyzed parameters. The equation is as follows:

$$\frac{\sqrt{\text{sum of cation}} - \sqrt{\text{sum of anions}}}{\sqrt{\text{sum of cations}} + \sqrt{\text{sum of anions}}} \times 100 \tag{1}$$

2.5. Computation of irrigation water quality

Chemical parameters such as EC, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, and HCO_3^- were considered in irrigation water quality index computation. Irrigation water indexes such as SAR, percentage sodium (Na%), RSC, SSP, PI, and KI were calculated and interrelated to assess groundwater quality for irrigation. Willcox or CS plot was also drawn to assess the irrigation quality of collected groundwater samples.

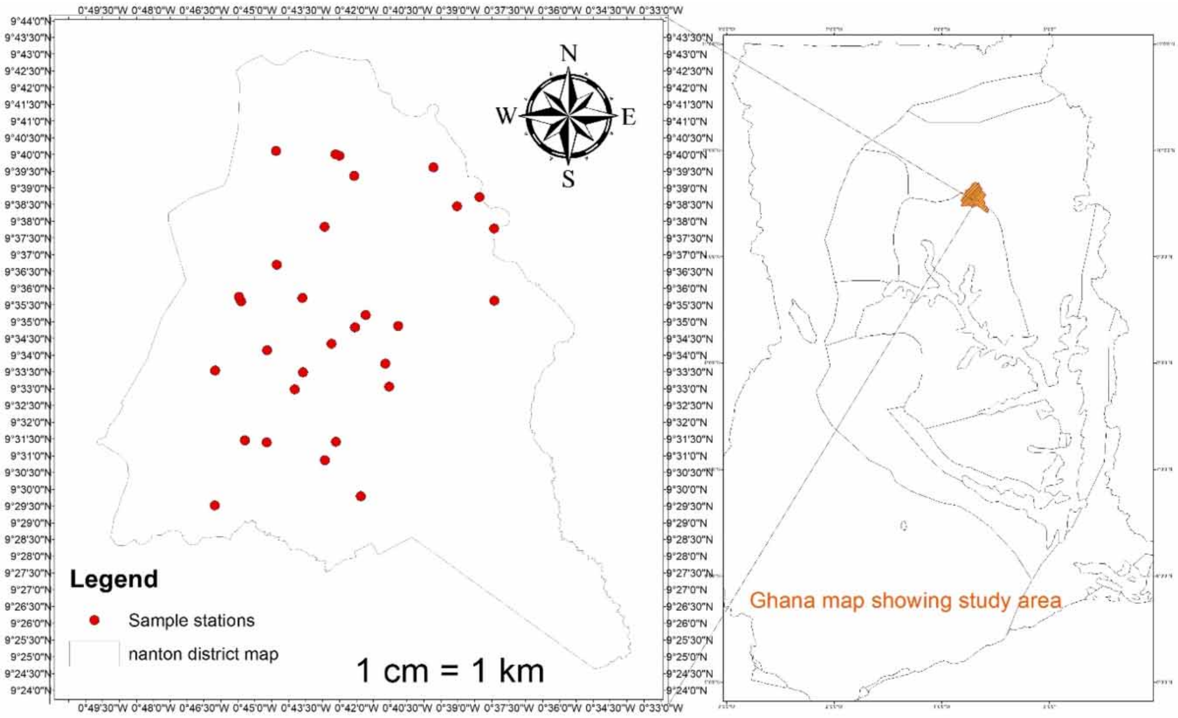


Figure 1 | Groundwater sample's location map.

2.5.1. Sodium adsorption ratio (SAR)

This was evaluated using the equation previously adopted by Al-Saffawi *et al.* (2020), Abbasnia *et al.* (2018), Singh *et al.* (2020), Bhat *et al.* (2016), and Chabuk *et al.* (2020):

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}{2}}} \tag{2}$$

2.5.2. Percentage sodium (Na%)

This was estimated using the equation previously adopted by Elsayed *et al.* (2020):

$$\mathrm{Na}\% = \frac{(\mathrm{Na}^{+} + \mathrm{K}^{+})}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+} + \mathrm{K}^{+})} \times 100 \tag{3}$$

2.5.3. Soluble residual carbonate (SRC)

This was computed adopting the equation previously adopted by Singh *et al.* (2020):

$$\mathrm{SRC} = \left(\mathrm{CO}_3^{2-} + \mathrm{HCO}_3^{-}\right) - (\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+}) \tag{4}$$

2.5.4. Soluble sodium percentage (SSP)

This was evaluated using the equation previously employed by Singh *et al.* (2020). All ionic concentrations were in meq/l.

The equation is as follows:

$$\mathrm{SSP} = \frac{(\mathrm{Na}^{+} + \mathrm{K}^{+})}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+} + \mathrm{K}^{+})} \times 100 \tag{5}$$

Table 1 | Groundwater sample stations and their coordinates

Station Name	Station ID	*X*	*Y*
Nyoligu	NY	−0.63233	9.62981
Zokugu	ZK	−0.6394	9.64543
Sindigu	SD	−0.65045	9.64079
Tigu	TG	−0.66211	9.66034
Kukuo	KK	−0.70115	9.656
Jegun	JG	−0.7085	9.66613
Zogu	ZG	−0.71029	9.66681
Kpanya	KN	−0.73967	9.66838
Batanyili	BT	−0.7158	9.63058
Nanton Kurigu	NK	−0.73928	9.61172
Zoonaayili	ZY	−0.63207	9.59383
Tampion	TP	−0.67943	9.5812
Looni	LN	−0.6955	9.5867
Digu	DG	−0.70074	9.58058
Gushei	GS	−0.71236	9.5724
Yapalsi	YP	−0.72665	9.59513
Gbumgbum	GG	−0.75692	9.59341
Afaya	AY	−0.75778	9.59572
Kpano	KP	−0.74412	9.56909
Kpachelo	KC	−0.76965	9.55905
Balshei	BS	−0.76985	9.4919
Dungwani	DW	−0.75502	9.52432
Zion	ZO	−0.74417	9.52324
Zetugu	ZT	−0.71561	9.51434
Guntingli	GT	−0.69785	9.49651
Kpunduli	KD	−0.71015	9.52362
Chehiyili	CY	−0.68387	9.55108
Sakpali	SK	−0.68577	9.562458
Sanvili	SV	−0.72637	9.55828
Nanton	NT	−0.7305	9.54967

2.5.5. Permeability index (PI)

This was computed using the equation by Elsayed *et al.* (2020):

$$\mathrm{PI} = \frac{(\mathrm{Na}^{+} + \sqrt{\mathrm{HCO}_3^{-}})}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+})} \times 100 \tag{6}$$

The ionic concentrations were in meq/l.

2.5.6. Kelly index (KI)

This was calculated using Elsayed *et al.* (2020) equation:

$$\mathrm{KI} = \frac{\mathrm{Na}^{+}}{(\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+})} \tag{7}$$

3. RESULTS AND DISCUSSION

3.1. Irrigation water quality based on pH, absolute ions, and EC

3.1.1. Irrigation water quality based on pH

This is a measure of the intensity of the acidic or alkaline nature of solutions. The recorded pH values of groundwater samples in this present study are between 5.61 and 8.44 with a mean value of 7.51. In a report by Schiavon & Moore (2021), the acceptable limit of pH for irrigation water is 6.5 (H^+ dominates on the acidic level) to 8.5 (OH^- dominates on the alkaline level). The research further highlighted that pH is seldom a problem in irrigation water. However, it serves as an indicator of potential issues when values fall outside or below the recommended range, such as excessive bicarbonates dissolved in irrigation water. This suggests that all groundwater samples in the study area are suitable for irrigation with respect to pH.

3.1.2. Irrigation water quality with respect to absolute ions

The concentrations of soil calcium, magnesium, and sodium are highly important. According to Schiavon & Moore (2021), calcium and magnesium play significant roles in bringing stability to soil structure (primarily calcium ions). However, excess application of sodium through irrigation water would displace the calcium ions from soil colloids, causing soil deflocculation and eventually permeability challenges (Schiavon & Moore 2021). This process breaks down the soil structure. The minimum and maximum cation concentrations recorded in the research area in this current study ranged from 6.01 to 54.30 mg/l for calcium, 1.20 to 28.70 mg/l for magnesium, 15.00 to 380 mg/l for sodium, and 1.10 to 8.0 mg/l for potassium with mean values of 24.67, 11.36, 108.60, and 2.56, respectively. According to Chhabra (2018), the permissible limit for these cation concentrations in irrigation water is 80, 35, 100, and 30 mg/l, respectively. On these bases, all groundwater samples in the study area are suitable for irrigation with regards to calcium, magnesium, and potassium. With respect to sodium, 63% of the samples are suitable for irrigation and 37% are not suitable.

According to Schiavon & Moore (2021), high concentrations of chloride anions can be toxic to plants when accumulated in their leaves. If chloride ions accumulate on the tips and margins of plant leaves, they induce the dehydration of plant cells, resulting in leaf chlorosis (Schiavon & Moore 2021). Also, carbonates and bicarbonates can combine with calcium and magnesium to form insoluble deposits in plants. As such, the acceptable limit for these anions in irrigation water is 250 mg/l as reported by Singh *et al.* (2020). In the study area, chloride, carbonate, and bicarbonate recorded minimum and maximum values ranging from 2.58 to 557 mg/l, 0.00 to 33.2 mg/l, and 61 to 551.0 mg/l, respectively. The mean values recorded for these ions were 66.7, 4.12, and 267.63 mg/l, respectively. On the basis of the acceptable limit, 97% of groundwater samples were within the limit for irrigation water with respect to chloride, while 3% were not suitable. Also, 53% of the groundwater samples were suitable for irrigation with respect to bicarbonate while 47% were not. However, all groundwater samples were suitable for irrigation with respect to carbonate.

3.1.3. Irrigation water quality with respect to electric conductivity (EC)

The EC of irrigation water is a measure of the total salinity and it is directly related to the total soluble salts as reported by Kosal-Sahin *et al.* (2019). Bruce & Hardeep (2016), in their report, state that nutrients are applied to crops in the form of salts that subsequently dissolve to create positive and negative ions. These ions form an aqueous solution that conducts electricity, measured as EC. Consequently, elevated EC values indicate an excess of nutrients in the water, which can lead to issues such as osmotic pressure, ion toxicity, and nutrient imbalances (Bruce & Hardeep 2016). Conversely, very low EC values may indicate insufficient nutrient levels in the water, negatively impacting plant growth. Therefore, maintaining a balanced EC value is crucial for effective irrigation water management. According to Bhat *et al.* (2016), the permissible limit for EC in irrigation water is in the range of >250 to 2,250 μs/cm. In the present study, the recorded EC values were in the range of 135 to 2,240 μs/cm. On this basis, all groundwater samples in the study area are suitable for irrigation purposes (Table 2).

3.2. Irrigation water quality with respect to irrigation water indexes

3.2.1. Irrigation water quality based on sodium adsorption ratio (SAR)

In a report cited by Singh *et al.* (2020), states that the alkali or sodium hazard of water is measured by SAR. This makes SAR one of the main parameters used to assess the quality of groundwater in an area for irrigation purposes. Irrigation water containing high concentrations of sodium ions has the potential of reducing soil permeability (Table 3). This limits the amount of air and water percolation in soils. According to Ndoye *et al.*

Table 2 | Statistical summary of absolute ions, pH, and electrical conductivity

Parameters	**Minimum**	**Maximum**	**Mean**	**Std. Error**
pH	5.61	8.44	7.51	0.12
Calcium	6.01	54.30	24.67	1.82
Magnesium	1.20	28.70	11.36	1.05
Sodium	15.00	380.00	108.60	16.95
Potassium	1.10	8.00	2.59	0.24
Carbonate	0.00	33.20	4.12	1.82
Bicarbonate	61.00	551.00	267.63	21.38
Chloride	2.58	557.00	66.70	20.61
Electrical conductivity	135.00	2,240.00	782.27	91.73

Table 3 | Calculated irrigation water quality indexes, their sample's locations, and coordinates

Station ID	***X***	***Y***	**SAR**	**Na%**	**RSC**	**SSP**	**PI**	**KI**
AY	−0.75778	9.59572	1.76	47.66	1.29	47.66	94.94	0.89
BS	−0.76985	9.4919	8.07	75.07	4.06	75.07	93.30	3.00
BY	−0.7158	9.63058	8.92	82.16	4.49	82.16	105.28	4.57
CY	−0.68387	9.55108	2.57	55.42	2.47	55.42	90.96	1.20
DG	−0.70074	9.58058	1.31	38.36	−0.19	38.36	75.22	0.60
DW	−0.75502	9.52432	2.90	59.33	2.32	59.33	99.16	1.43
GG	−0.75692	9.59341	3.53	67.09	1.82	67.09	105.87	2.02
GS	−0.71236	9.5724	1.61	43.13	0.87	43.13	85.69	0.74
GT	−0.69785	9.49651	12.82	84.43	−0.33	84.43	92.80	5.40
JG/WELL	−0.7085	9.66613	1.13	52.12	0.33	52.12	117.70	0.97
KC	−0.76965	9.55905	5.09	71.45	4.02	71.45	104.59	2.49
KD	−0.71015	9.52362	8.67	81.39	4.00	81.39	103.04	4.32
KK	−0.70115	9.656	5.93	74.51	3.09	74.51	101.10	2.89
KN	−0.73967	9.66838	6.28	73.01	5.41	73.01	100.53	2.68
KP	−0.76965	9.55905	1.18	34.30	−0.65	34.30	66.62	0.49
LN	−0.6955	9.5867	2.64	54.71	1.26	54.71	88.26	1.18
NK	−0.73928	9.61172	2.82	51.47	1.94	51.47	81.90	1.04
NT	−0.7305	9.54967	1.35	38.42	0.16	38.42	76.85	0.60
NY	−0.63233	9.62981	1.63	44.43	1.05	44.43	86.81	0.76
SD	−0.65045	9.64079	6.17	77.22	3.93	77.22	108.88	3.37
SK	−0.68577	9.562458	1.76	47.51	1.15	47.51	90.21	0.86
SV	−0.72637	9.55828	9.93	87.24	4.17	87.24	112.39	6.80
TG	−0.66211	9.66034	4.36	68.89	3.21	68.89	103.61	2.19
TP	−0.67943	9.5812	2.18	50.18	1.19	50.18	88.51	0.99
YP	−0.72665	9.59513	1.18	35.49	0.75	35.49	81.58	0.53
ZG	−0.71029	9.66681	2.44	60.17	1.82	60.17	110.58	1.47
ZK	−0.6394	9.64543	3.41	76.85	1.49	76.85	135.78	3.26
ZN	−0.63207	9.59383	15.89	88.56	6.88	88.56	103.39	7.65
ZO	−0.74417	9.52324	3.27	60.32	3.70	60.32	95.36	1.48
ZT	−0.71561	9.51434	5.94	71.60	4.65	71.60	96.84	2.50

(2018), there is an exchange process that occur between soil and water. Thus, the sodium ions are adsorbed by clay particles in soils replacing the calcium and magnesium ions which are responsible for building soil structure. These processes destroy soil structure making it difficult to support plant growth. From the calculated SAR values presented in Tables 4 and 5, 93% of groundwater samples in the study area is suitable for all types of crops and soil except for corps sensitive to sodium. The remaining 7% of the samples are suitable for coarse textured or organic soil with permeability. On this basis, all groundwater samples showed suitability for agriculture activities.

Table 4 | Classification of groundwater samples based on calculated irrigation water indexes

Indexes group	Range	Class of water	Number of samples	Percentage	References
SAR (meq/l)	< 10	Excellent	28	93%	(Bhat *et al.*, 2016)
	10 to 18	Good	2	7%	
	10 to 26	Doubtful	N/A		
	> 26	Unsuitable	N/A		
Na% (meq/l)	< 20	Excellent	N/A		(Elsayed *et al.*, 2020)
	20 to 40	Good	4	13%	
	40 to 60	Permissible	10	33%	
	60 to 80	Doubtful	11	37%	
	> 80	Unsuitable	5	17%	
RSC (meq/l)	< 1.25	Safe	10	33%	(Rawat *et al.*, 2018)
	1.25 to 2.50	Permissible	8	27%	
	> 2.50	Unsuitable	12	40%	
SSP (meq/l)	<20	Excellent			(Singh *et al.*, 2020)
	20 to 40	Good	4	13%	
	40 to 60	Permissible	10	33%	
	60 to 80	Doubtful	11	37%	
	> 80	Unsuitable	5	17%	
PI (meq/l)	> 75(class I)	Excellent	29	97%	(Nag & Das, 2014)
	25 to 75(class II)	Good	1	3%	
	< 25(class III)	Unsuitable	N/A		
KI (meq/l)	< 1	Suitable	10	33%	(Rawat *et al.*, 2018)
	> 1	Unsuitable	20	67%	

Table 5 | Groundwater suitability for irrigation with respect to SAR values

SAR range	Suitability for irrigation	Percentage of samples	Reference
<10	Suitable for all types of crops and soil except for crops sensitive to sodium	93	Ndoye *et al.* (2018)
10–18	Suitable for coarse textured or organic soil with permeability	7	
10–26	Harmful for almost all soils	N/A	
>26	Unsuitable for irrigation	N/A	

3.2.2. Irrigation water quality based on percent sodium (Na%)

In addition to alkali or sodium hazard, saline irrigation water could lead to concentrations of certain ions high enough to cause damage to crops and decrease the yield of sensitive crops, known as specific ion toxicity (Chhabra 2018). Sodium is one of the most concerning ions in this regard. Even though sodium ion is essential to plant growth at low concentrations, it can cause toxicity to sensitive crops at high concentrations. According to Elsayed *et al.* (2020), the acceptable limit of percentage sodium ion concentration in irrigation water is in the ranges of less than (<)20 (excellent), 20–40 (good), 40–60 (permissible), 60–80 (doubtful), and greater (>)80 (unsuitable). Based on this, 13, 33, 37, and 17% of groundwater samples in the study area are within good, permissible, doubtful, and unsuitable conditions for irrigation as presented in Table 4.

3.2.3. Irrigation water quality with respect to residual sodium carbonate (RSC)

The concentrations of carbonates and bicarbonate ions more than that of calcium and magnesium ions influence the suitability of groundwater for irrigation. The excess concentrations of carbonates and bicarbonate ions are referred to as RSC. According to Singh *et al.* (2020), higher RSC values are an indication that much of the calcium and some magnesium ions get precipitated from the groundwater. This increases the percentage of sodium in water and soil particles thereby increasing the possibility of sodium hazard. In a report cited by Rawat *et al.* (2018), the index ranges for RSC are <1.25 (safe), 1.25–2.5 (permissible), and >2.5 (unsuitable).

On the basis of this, 33% of groundwater samples in the study area are safe for irrigation, 27% are permissible and 40% are unsuitable (Tables 4 and 6).

Table 6 | RSC classification of groundwater and the hazards

RSC range	Quality	Hazard	Percentage of samples	Reference
<1.25	Safe	Low with some removal of calcium and magnesium from irrigation water	33	Singh *et al.* (2020)
1.25–2.50	Permissible	Medium with appreciable removal of calcium and magnesium from water	27	
>2.50	Unsuitable	High with most calcium and magnesium removed leaving sodium to accumulate	40	

3.2.4. Irrigation water quality based on soluble sodium percent (SSP)

In addition to RSC, SSP is a significant indexing parameter used to estimate soil permeability. According to Singh *et al.* (2020), high levels of SSP in groundwater influence ion exchange between calcium and magnesium ions in soil. The process affects the soil's structure and reduces permeability. Also, groundwater with a high percentage of SSP influences the reaction of sodium ions with chloride and carbonate ions. These reactions cause soils to be more alkaline or saline in nature. Increased alkalinity or salinity of soils affects the growth of plants and crop yield (wilting). The classification of groundwater for irrigation based on SSP is given by Singh *et al.* (2020) (Table 4). On the basis of these classifications, 13%, 33%, 37% and 17% of groundwater samples in the study area are within good, permissible, doubtful and unsuitable conditions for irrigation as presented in Table 4.

3.2.5. Irrigation water quality on the basis of permeability index (PI)

According to Rawat *et al.* (2018), the PI is a formula developed to assess the soil's water permeability capabilities and the suitability of any water source for irrigation. Understanding this process makes PI significant for assessing the quality of groundwater for irrigation purposes. In a report by Bhat *et al.* (2016), groundwater can be classified into class I, class II, and class III according to PI. Classes I and II are characterized as excellent and good for irrigation with 75% or more of maximum permeability as presented in Table 4. However, class III is unsuitable with a 25% of maximum permeability (Table 4). Based on the PI values computed for this study, 97% of groundwater samples in the study area are excellent for irrigation purposes while the remaining 3% are good for irrigation.

3.2.6. Irrigation water quality with respect to Kelly index (KI)

According to Elsayed *et al.* (2020), KI exposes the amount of excess sodium ions in groundwater. Groundwater samples with KI value < 1 are suitable for irrigation while values >1 are unsuitable (Table 4). In accordance with KI values, 33% of groundwater samples in the study area are suitable for irrigation while 67% are not.

3.2.7. Irrigation water quality based on United State Salinity Laboratory diagram (USSL)

From the USSL diagram (Figure 2), 97% of groundwater samples in the study area were plotted within C1S1, C2S1, C3S2, and C3S3 regions. This shows that the majority of groundwater sources in the study area can be used for irrigation purposes. However, 3% of the samples plotted in the C3S4 indicating high salinity and very high sodium hazard. This suggests that such groundwater sources are not suitable for irrigation. The recorded

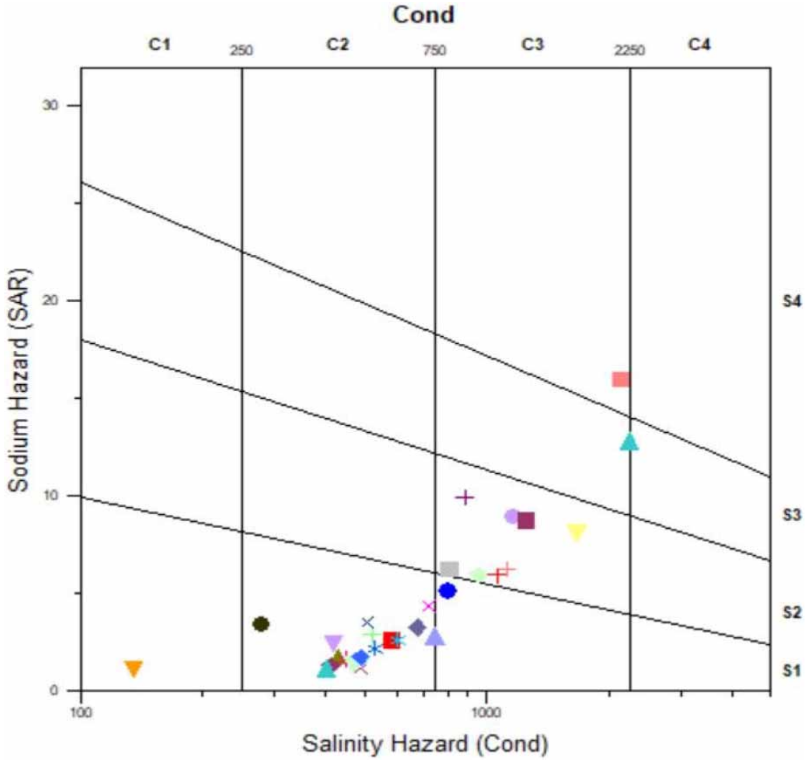


Figure 2 | Classification of groundwater on the basis of USSL. C: Salinity Hazard; C1: Low, C2: Medium, C3: High, C4: Very high. S: Sodium hazard; S1: Low, S2: Medium, S3: High, S4: Very high.

salinity and sodium hazard in the study area could be attributed to the significant dissolution of dolomite and calcite rocks in groundwater since the study area is not close to any form of seawater.

4. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the research found that most chemical parameters met the permissible limits for irrigation. However, Cl^-, HCO_3^-, and Na^+ ions displayed varying levels of suitability, with some falling outside the acceptable range. Also, the evaluation of various irrigation water quality indices yielded positive results for SAR, PI, SSP and Sodium percentages, with the majority falling into the Excellent or Good categories. However, the KI, and RSC values indicated a significant proportion of samples that were doubtful or unsuitable for irrigation. The USSL diagram also showed a majority of the samples plotting in the C1S1, C2S1, C3S2, and C3S3 regions and a few in the C3S4 region. The samples plotted in the C3S4 region shows high salinity and very high sodium hazard and therefore cannot be used for irrigation purpose. This observation in high salinity could be attributed to the significant dissolution of rock minerals or ion exchange contributing Cl^-, Na^+, and HCO_3^- ions in groundwater within those areas. Due to the significant amount of salinity and sodium hazard levels shown in some areas, further research should be conducted in the area to assess the quality of groundwater for drinking and domestic uses. The research should also emphasize identifying the factors that could be controlling groundwater chemistry and quality in the area. In addition, the current study could not include any further analyses of toxic and heavy metals. As a limitation of this work, we recommend further studies examining the concentrations of other toxic and heavy metals, and the use of GIS and modeling techniques for a more comprehensive understanding of the suitability of groundwater for irrigation. It is hoped that the information provided by this research would help policymakers take the necessary steps to provide sustainable agriculture in the study area.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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