Suitability of Groundwater in Auchi and Its Environs for Irrigation Purposes

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ABSTRACT

The study was conducted to assess the suitability of the groundwater in Auchi and evirons, Edo State, Nigeria for irrigation purposes. The parameters used to assess the irrigation suitability of the groundwater are: total dissolved solids (TDS), electrical conductivity (EC), sodium absorption ratio (SAR), soluble sodium percentage (SSP), residual sodium bicarbonate (RSBC), permeability index (PI), kelly ratio (KR), magnesium adsorption ratio (MAR), and total hardness (TH). The mean concentration of pH, TDS, EC, and TH are 5.8, 67.0 mg/l. 134.0 µs/cm, and 11.5 mg/l, respectively. The average SAR value is 0.16 meq/l while the mean value of MAR is 32.7%. The average value of SSP is 21.7% while mean RSBC values is 0.15 meq/l. The average value of PI is 23.8 % while the mean value of KR is 0.25 meq/l.

The results of these findings revealed that the groundwater sample within the study area is suitable for irrigation purposes. The low salinity and magnesium hazards that characterized the groundwater system within the area further support the irrigation usability. The hydro-chemical facies classification using Piper diagram revealed the water-type in the area is Ca-Cl type, an indication of marine interaction. Based on these findings, private and commercial farmers in Auchi and environs can now use the groundwater system in the area for irrigation agriculture.

(Keywords: suitability, groundwater, irrigation purposes, physicochemical characteristics, Auchi, Edo State, Nigeria).

INTRODUCTION

The significance of water quality in irrigation scheme is pertinent to sustainability of agricultural productivity. The physicochemical characteristics of water determine its use either for domestic, irrigational, or industrial purposes [1]. The Food and Agriculture Organization (FAO) amongst others have proposed various irrigation water quality criteria of which the physical and chemical properties of water has a more significant effects on the irrigation water quality as compared to the biological properties of the water [2].

Most irrigation schemes fail because the quality of water used for irrigation, does not meet the standard for irrigation water as stipulated by globally accepted regulators such as FAO. This poses serious threat to soil, plant, livestock, and the environment. Water occurs as surface and groundwater, its quality is affected by a wide range of natural and human factors. Surface water is usually more prone to natural and anthropogenic pollution compared to groundwater [3], although for irrigation purposes groundwater might pose more threat than surface water due to the increases salinity in groundwater compared to surface water [4]. In arid and semi-arid areas characterized by low rainfall and high evaporation rates, groundwater is the most convenient water source for irrigation. Crop irrigation is one of the most extensive applications of groundwater in the world [5, 6].

The salinity hazard increases the osmotic pressure of the soil water and restricts the plant roots from absorbing water, despite its availability, thereby resulting in a physiological

drought condition [7]. The parameters employed for the study include electrical conductivity, total hardness, sodium absorption ratio, magnesium adsorption ratio, Kelly ratio, soluble sodium percentage, permeability index, and residual sodium bicarbonate.

The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts (salinity hazard) and high sodium content (sodium hazard) with the soil is worrisome, hence the need to ascertain the suitability of groundwater in Auchi area before use by farmers for irrigating their crops. Several irrigation farms within Auchi utilize groundwater for their irrigation due to the seasonal nature of surface water in the area, thus there is need to assess the quality of the groundwater in study area for effective and efficient irrigation farming in the area.

MATERIALS AND METHODS

Study Area Description

The study area is situated between latitudes 7º00' N to 7o10' N of the Equator and longitudes 6º10' E to 6º20' E of the Meridian. The study area is accessible through the Benin-Auchi-Abuja road (Figure 1). The area is characterized by dry and wet seasons, the dry season usually occurs between December-March; and the wet season spans from April-November. The vegetation of the area falls within the guinea savannah, which is dense during the rainy season and less dense during the dry season. The study area has an undulating topography with a rugged relief. The area is characterized by dentrital drainage system and is drained by River Orle and River Niger.

Geology and Hydrogeology of the Study Area

The study area lies within the Anambra Basin, which is a structural depression located at the Southern Benue Trough. The Southern Benue Trough covers a large set of different lithologies namely: Albian Asu River Group, Turonian Eze-Aku Formation, Coniacian Awgu Formation, Campano-Maastrichtian Nkporo Group, Maastrichtian Mamu, Ajalli and Nsukka Formations, Paleocene Imo Shale, Eocene Ameki Formation and the Late Eocene Ogwashi-Asaba Formation [8]. These rock types were deposited in succession/horizontal layers starting with the oldest Albian Asu River Group) at the bottom and the youngest (Late Eocene Ogwashi-Asaba Formation) at the top (Figure 2).

Hydrogeologically, the Ajali Formation is the aquiferous formation in the study area. The groundwater in the study area is recharged by rainfall (precipitation) while the chemistry is greatly modified by surface water-groundwater interaction.

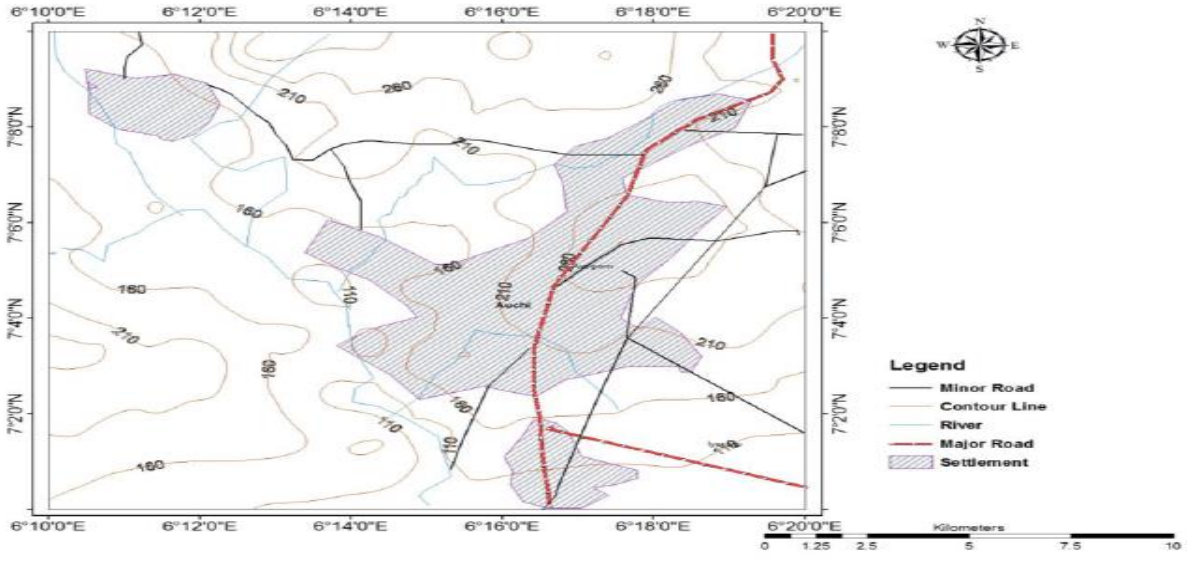

Figure 1: Location Map of the Study Area.

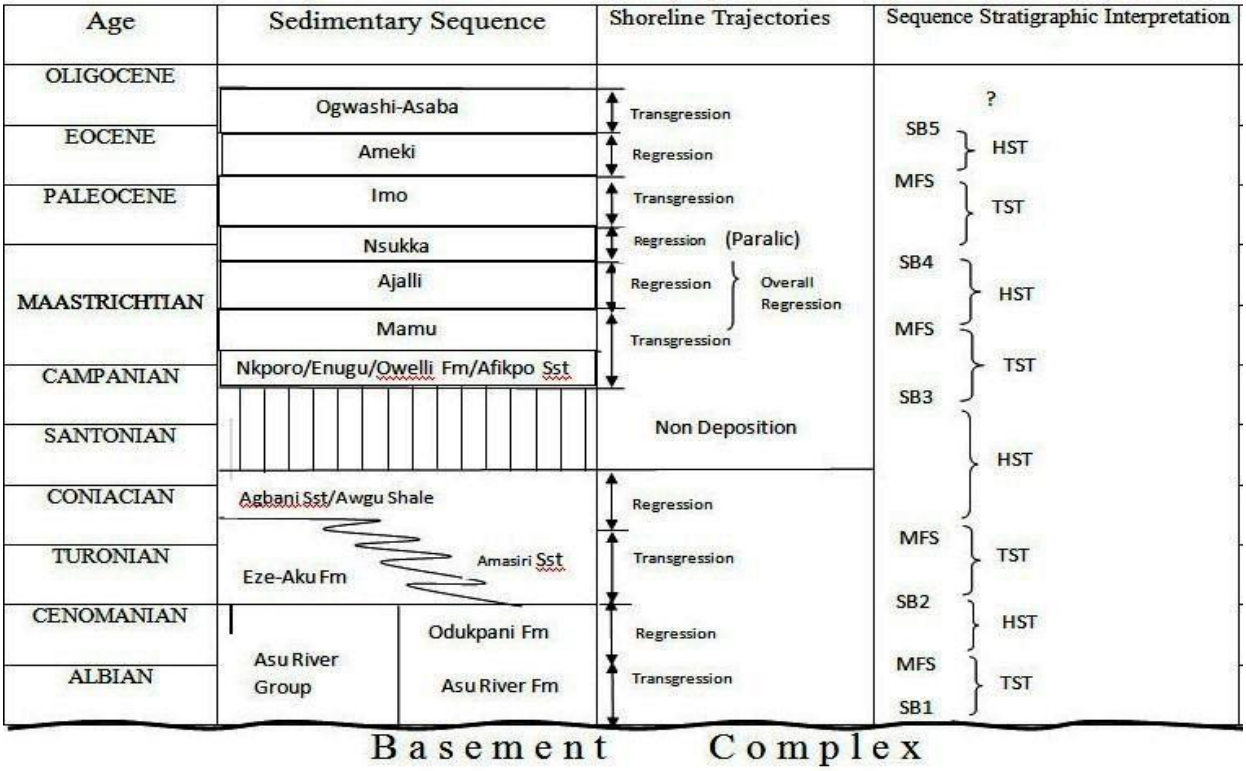

Figure 2: Stratigraphic Succession of the Southern Benue Through [8].

Methodology

Thirty (30) groundwater samples were collected in two sets of one-liter containers for geochemical analyses. Critical physical parameters such as temperature, electrical conductivity, pH and total dissolved solids were measured *in situ* with the aid of a Model PHS-3B three in one multi-meter. The laboratory analysis of the groundwater samples was done with the aid of an Atomic Absorption Spectrophotometer (AAS), Spectronic 20D+ spectrophotometer, Oven, Incubator and Titration apparatus. The results of the laboratory analyses were converted from mg/l to meq/l and then used for the computation of the various irrigation water quality parameters as highlighted below:

$$\textbf{SAR} = \frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \quad \textbf{(1)}$$

(Richards, 1954),

$$\textbf{MAR} = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} * 100 \quad \textbf{(2)}$$

(Szobolces and Darab, 1968),

$$\textbf{SSP} = \frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^+ + K^+} * 100 \quad \textbf{(3)}$$

(Todd, 1980),

$$\textbf{KR} = \frac{Na^+}{Ca^{2+}+Mg^{2+}} \quad \textbf{(4)}$$

(Kelly, 1963),

$$\textbf{RSBC} = (HCO_3^- + CO_3^{2-}) - Ca^{2+} \quad \textbf{(5)}$$

(Gupta and Gupta, 1987),

$$\textbf{PI} = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+} * 100 \quad \textbf{(6)}$$

(Doneen, 1962),

TH = $(Ca^{2+} + Mg^{2+}) * 50$ **(7)**
(Raghunath, 1987).

RESULTS AND DISCUSSION

The summary of the physical parameters obtained *in situ* in the field and laboratory analyses of major ions are presented in Table 1 while the summaries of computed irrigation indices are shown in Table 2. Classification of water using irrigation indices are shown in Tables 3 and 4, respectively.

The water temperature ranged from 26.0 °C to 27.8 °C with an average value of 26.8 °C, and these values falls within the permissible ambient temperature. One good attribute of groundwater is its almost constant temperature, which is advantageous for crop productivity and management.

The concentration of EC (49.1-580.4) and TDS (24.8-290.3) falls within their respective permissible limit of 700.0 us/cm and 450.0 mg/l, respectively, as recommended by Food and Agricultural Organization (FAO). Similarly, the concentrations of the major cations and anions are far below their respective maximum allowable limits, an indication that the groundwater system will be suitable for irrigational use.

The average Total Hardness (TH) of groundwater samples in the study area is 13 mg/l, the groundwater system in the study area has a hardness lesser than 75 mg/l and thus falls into soft water category. The FAO proposed TH not higher than 150 mg/l as ideal for irrigation purpose. The TH of groundwater in the area are within recommended FAO limit, hence the groundwater in Auchi area is suitable for irrigation. Water hardness is generally controlled by the concentration of Ca and Mg ions present in the water. The Ajali formation (sandstone) is aquiferous zone in the study area based on the lithostratigraphy of the area.

Table 1: Summary of Laboratory Results of the Groundwater from Auchi Area.

Parameters (mg/l)	*Minimum*	*Maximum*	*Mean*
Temp (°C)	26.00	27.80	26.84
EC (us/cm)	49.10	580.40	133.95
TDS	24.80	290.30	67.15
Sodium	0.76	7.53	1.74
Potassium	0.12	1.10	0.28
Calcium	1.45	13.80	3.60
Magnesium	0.50	4.73	1.15
Chloride	15.20	145.10	27.10
Bicarbonate	10.20	96.70	38.17
Sulphate	0.14	1.41	0.61

Table 2: Results of Groundwater Quality Parameters for Irrigation Purposes in Auchi Area.

Irrigation Indies	SAR (meq/l)	MAR (%)	PI (%)	RSC (meq/l)	SSP (%)	KR (meq/l)	TH (mg/l)	EC (µ/cms)	TDS (mg/l)
MIN	0.118	30.490	15.290	0.068	19.064	0.210	5.907	49.100	24.800
MAX	0.204	36.223	34.099	0.257	25.627	0.318	22.607	580.400	290.300
MEAN	0.161	32.657	23.756	0.158	21.723	0.254	11.521	133.947	67.150
FAO Value	<3	<60	<60	<2.5	<60	<1	50 - 150	<700	<450
Remark	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable

Table 3: Classification of Irrigation Water using EC, RSBC, SAR, SSP and PI [12, 13, 14].

Category	EC (µS/cm)	RSBC (meq/l)	SAR	SSP (%)	PI (%)	Remark
I	<117.51	<1.25	<10.0	<20.0	<80.0	Excellent
Ii	117.51-508.61	1.25-2.5	10.0-18.0	20.0-40.0	80.0-100.0	Good
III	>508.61	>2.5	18.0-26.0	40.0-80.0	100.0-120.0	Fair
IV	–	–	>26.0	>80.0	>120.0	Poor

EC-electrical conductivity; RSBC-residual sodium bicarbonate; SAR-sodium adsorption ratio; SSP-soluble sodium percentage; PI-permeability index

Table 4: Classification of irrigation water based on TDS, MAR and KR [15, 16, 17].

Class	MAR (%)	KR (meq/l)	TDS (mg/l)	Suitability for Irrigation
I	<50.0	<1.0	<500.0	Suitable
II	>50.0	>1.0	>500.0	Unsuitable

MAR-magnesium adsorption ratio; KR-kelly's ratio; TDS-total dissolved solids.

Soluble Sodium Percentage (SSP)

The percent of sodium is an important factor in irrigation evaluation as it leads to stunted growth in crops and reduces soil permeability [12]. Soluble sodium percentage (SSP) of the groundwater in the study area is 22.0%. Water with SSP value of < 60.0% is suitable for irrigation [10]. It implies that the SSP of the groundwater is suitable for irrigation purposes (Tables 2 and 3).

The SSP values were plotted against the EC values on the Wilcox diagram and the groundwater samples fall under the excellent to good category (Figure 3). Also high sodium concentration in soil can affect the internal drainage patterns as the release of calcium and magnesium ions in soil solution [11].

Salinity Hazard

The average sodium adsorption ratio (SAR) of the groundwater in the study area is 0.16 meq/l. The SAR of the groundwater in the study area is less than 3.0 meq/l which is the standard stipulated by [18]. The salinity hazard plot revealed that all the sampled groundwater in Auchi area falls within the low SAR (S1) region (Figure 4), which signified it can be excellently used for irrigation.

Similarly, in the EC axis, about 90% also fell on the low EC (S1-C1) region, while samples number 17, 18 and 22 constituting about 10 % of the entire samples fell within the low sodium-medium EC region (S1-C2).

The SAR plots confirmed that the groundwater in Auchi area is suitable for crop production.

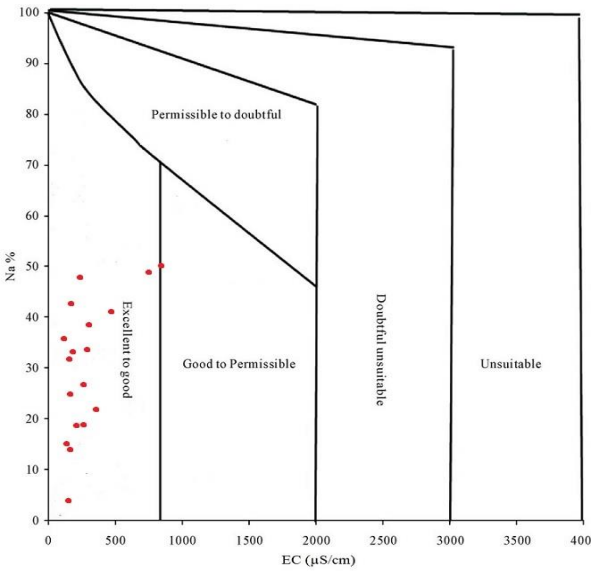

Figure 3: Wilcox Diagram for the Study Area.

The implication of the salinity hazard plot indicates that the groundwater in the study area has low salinity hazard, hence suitable for irrigation purposes (Tables 2 and 3).

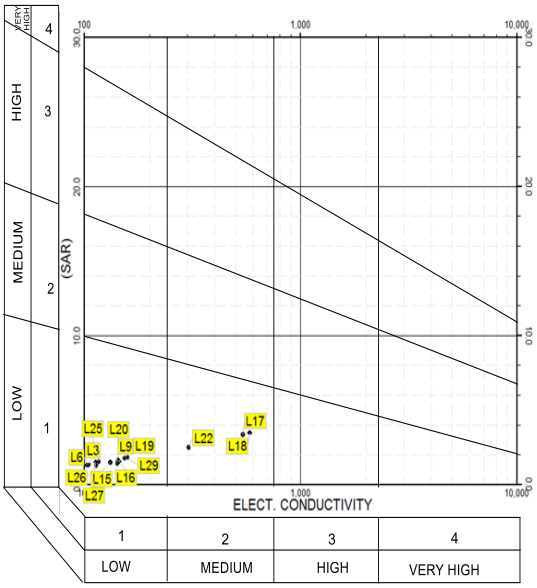

Figure 4: Salinity Hazards Plot for Auchi Area.

Magnesium Adsorption Ratio (MAR)

The magnesium adsorption ratio (MAR) evaluates the concentration of Mg in relation to Ca, high Mg content in relation to Ca poses a threat to soil quality, it reduces the porosity and eventually permeability of the soil thus inhibiting soil water circulation and availability. According to [18], MAR value below 60.0 % is suitable for irrigation. The average MAR value in the study area is 33.0 % thus is considered suitable for irrigation and there is no magnesium hazard.

The average Kelly's ratio (KR) of the groundwater in the study area is 0.25 meq/l. Waters with a Kelly's ratio value of <1 are suitable for irrigation, and those >1 are unsuitable for irrigation purposes [19]. Thus the KR of the groundwater in Auchi area is suitable for irrigation.

Residual Sodium Bicarbonate (RSBC)

The residual sodium bicarbonate (RSBC) of the groundwater in the study area is 0.16 meq/l. The RSBC value ≤1.25 meq/l is considered good quality, 1.25 - 2.5 meq/l is moderately good for irrigation while RSC value >2.5 meq/l, is considered unsuitable for irrigation and harmful to crops [19, 20]. Thus, the RSBC value of the groundwater in the study area is very good and suitable for irrigation.

The average permeability index of the groundwater in the study area 24.0 %, this is less than the 60.0 % set by the FAO as the standard for irrigation water. The SAR, SSP and KR criteria are used to evaluate and ascertain sodium toxicity, a critical parameter in irrigation studies [21]. High level of sodium in groundwater over a long period of time affect the permeability of the soil irrigated with such water.

Permeability Index (PI)

Permeability index measures the concentration and solubility of sodium in relation to other cations present in the water (Ca, Mg and K) as well as the bicarbonate concentration of the water [22, 23]. The value of PI ranged from 15.26 % to 34.10 % with a mean value of 23.76 %. Permeability Index is classified under the following: class 1, which signified excellent to very good permeability, class II, reflecting good to moderate permeability and class III, which implies poor to very poor permeability respectively [18].

Interestingly, the groundwater samples in Auchi area fell on class I and II, which indicate that the groundwater system can be suitably used for irrigation agriculture. Based on the plots generated from SSP, SAR and PI, it has been established that the groundwater system in the area is suitable for irrigation purpose.

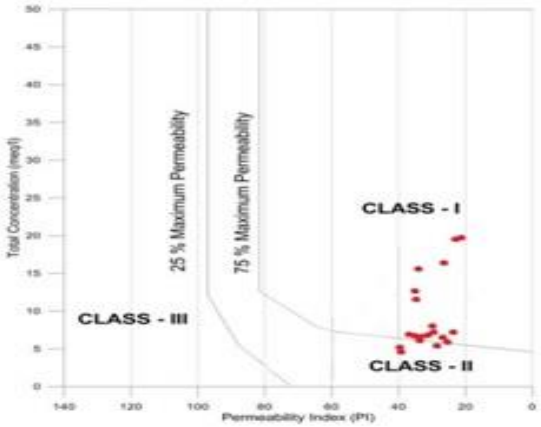

Figure 5: Doneen's Chart for Permeability Index values

Correlation of Irrigation Quality Parameters

The relationship between the various irrigation water quality guides was revealed in a simple correlation carried out on the results of the computed parameters (Table 5). A strong positive correlation exists between SAR, SSP and KR which is likely due to the fact that they assess sodium hazard in soils. There is also a strong positive correlation between TDS and EC which is due to the fact that the amount of solutes dissolved in water makes it to be conductive.

Hydrochemical Facies

The groundwater sample in the study area was classified, by the use of Piper diagram (Figure 6). The hydrochemical facies analysis revealed that the predominant ions in the groundwater in the study area are calcium and chloride, an indication of possible marine source. Based on the Piper diagram, the water type in the area is Ca-Cl type. In the course of plotting the Piper diagram, it is remarkable to note that the plot of 30 locations is appearing like few locations because the superimposed on each other. This implies that the groundwater system in the area has same source and origin [24, 25].

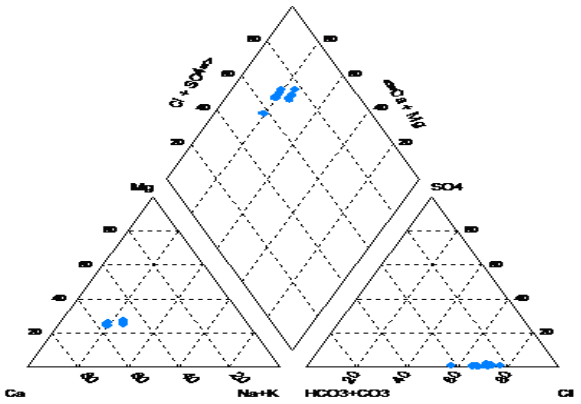

Figure 6: Piper Diagram for Auchi Area.

CONCLUSION

Groundwater is gaining more acceptability as a source of irrigation water due to the seasonal nature of most surface water bodies in Nigeria. The suitability of groundwater in and around Auchi town in Edo State, Nigeria was evaluated in this study.

Table 5: Correlation Analysis of Computed Irrigation Quality Parameters from Auchi Area.

	SAR	MAR	PI	RSBC	SSP	KR	TH	pH	EC	TDS
SAR	1									
MAR	0.432	1								
PI	-0.227	0.431	1							
RSBC	0.091	-0.334	0.280	1						
SSP	0.493	0.920	0.351	-0.467	1					
KR	0.494	0.920	0.354	-0.463	0.999	1				
TH	0.671	-0.165	-0.222	0.626	-0.186	-0.184	1			
pH	0.097	0.588	0.145	-0.499	0.626	0.624	-0.353	1		
EC	0.342	0.219	0.150	0.213	0.201	0.202	0.405	0.238	1	
TDS	0.342	0.217	0.149	0.215	0.198	0.200	0.407	0.236	0.999	1

The results of the computed irrigation quality indices confirmed that groundwater in Auchi area has a very low salinity and sodium hazard, and very suitable for use as irrigation water. The TDS, EC and TH values also indicate that the groundwater can be used as irrigation water. Hydrogeologically, the Ajali Sandstone is the main aquiferous unit in the area and the groundwater system is recharged via precipitation. The water type as shown on Piper diagram is Ca-Cl, an indication of marine source. Based on the computed values of the following irrigation indices: SAR, MAR, RSBC, SSP, PI and KR, it has been ascertained that the groundwater system in the area is suitable for irrigation purposes. It is recommended that farmers in Auchi area should use the groundwater resources for irrigation.

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