AN ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION PURPOSES IN KALTUNGO LOCAL GOVERNMENT, GOMBE STATE, NIGERIA

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ABSTRACT

There is growing need for irrigation due to scarcity of food and inflation in Nigeria. However, the quality of the groundwater affects the crops yield. This study assessed the suitability of groundwater resources in basement complex aquifers of Kaltungo and environs for irrigation purposes. A total of 40 groundwater samples were collected from hand-dug wells and boreholes during the peak period of the dry season. These samples were analyzed for major cations and anions concentrations. The physicochemical characteristics (PH, total dissolved solids (TDS), Electrical conductivity (EC), Alkalinity, Hardness, basic cations, anions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, NO_3^{-}, Fe^{2+} and F^{-}) present were determined. Irrigation quality indices models such as Electrical conductivity (EC), sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Kelly ratio (KR), sodium hazard (%Na), soluble sodium percentage (SSP), permeability index (PI) and magnesium hazard (MH) were evaluated. The results indicate that a maximum of six (6) samples representing 15% of the samples recorded high values of SAR and were observed to be higher than the recommended limits for irrigation. Other Irrigation indices evaluated for all the samples are found suitable at 100% for EC, 60% for MH, 85% for SAR, 100% for %Na, 100% for PI, and 53% for KR models. Generally, the groundwater in the study area is suitable for irrigation, although sustainability of the groundwater based on its quality should be investigated so as to keep monitoring of the yield of the agricultural produce in the research area.

Keywords: Groundwater quality, irrigation indices, and Kaltungo

1 INTRODUCTION

Agriculture is considered one of the most essential ingredients of Nigeria's political and social economy. Recently, certain portions of the agricultural farm lands depend on irrigation. This is largely due to uneven rainfall distribution in the area which necessitates the need to enhance soil moisture [1]. Countries where river systems and rainfall drainage are insufficient; groundwater has remained the most significant source for irrigation and has improved crops yield. Therefore, irrigation

practice has many advantages that could be both direct and indirect. The advantages include: prevention of famine, floods management, better yield of cash crops, d and provision of financial prospect for the farmers. The surface and groundwater are the two major sources of water available for irrigation purposes. However, [2] reported that in many countries where groundwater availability surpassed surface water, insufficient and uneven distribution of rainfall become rampant, groundwater become the primary sources of water for irrigation purposes. Recently, Nigeria is facing high food inflation and scarcity. To contain the challenges of food security in Nigeria, [3] stressed that serious attention should be given to irrigation farming. [4] Reported that in the areas characterized by the basement complex rocks, groundwater supply could meet the water requirement demand of a small-scale irrigation project. Though, the usage of the groundwater for irrigation depends on its quality. The quality of groundwater is contributed by many factors such as hydro-geochemical process in the aquifer, rainfall intensity infiltration, abstraction of water, source of the water, and aquifer recharge [5, 6, 7, 8, 9]. Groundwater may have high salinity, and alkalinization of the soil [7, 10, 11, 12] that can affect it suitability for irrigation. The salinity of the groundwater is measures by Electrical conductivity (EC) of the water. Low quality water usually contains dissolved salts and irrigation using saline water lead to the accumulation of salts which affect the growth of crops [13] and irreparable damage to the soil and the environment [14]. Various ionic concentrations of heavy metals, major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (Cl^{-}, HCO_3, SO_4^{2-}, NO_3^{-}, PO_4^{3-}, H_4SiO_4) are used as proxies of salinity and water quality [15, 16]. These cations and anions concentration have significance impact on the properties of the soil and the crop yield [17, 18]. Despite the importance of water quality on irrigation, data showing the suitability groundwater for irrigation in the Kaltungo is lacking. Hence, there is need for proper evaluation of groundwater quality for irrigation. This study aims to evaluate the quality groundwater in the area for irrigation purpose.

2 THE STUDY AREA

Kaltungo area is located along the Gongola sub-basin in the northeastern part of Nigeria. The area lies between Latitudes 9°45'00"N and 9°51'00"N and Longitudes, 11°15'00"E and 11°21'00"E and it covers an area of about 121km^2, which lies between north latitudes of 12°47′and 11°49′and east longitudes 78°61′ and 80°03′. The annual temperature is around 26 to 34°C, reflecting tropical to sub-tropical continental climate. It is also characterized by two seasons; a rainy season, which starts in April and ends in October and the dry season, which normally spans between November and April. In addition, more than half of the research area in the northern part of Nigeria is covered by vegetation of a typical Sudan Savannah type, distinguished by its short grasses, scattered trees and sporadic thorny bushes. The topography of the area is generally hilly at the center of the town and valleys to the southeastern part of the area as define by the elevation (Figure 1). However, the drainage system in the area comprises various streams that emptied its sediments and water into River Gongola which flows towards the southeast [7].

2.1 Geological setting

The Benue Trough (Figure 1) is defined as an intracontinental rift basin, and that traced its origin to the West Central African Rift System (WCARS), which led to the opening of the South Atlantic Ocean, as African continent separated from South America during the Mesozoic [19]. In to the African continent, the trough extends for about 800–1000 km long, with a continuous width of about 150-250 km [20, 21]. The Benue Trough is filled with about 6000m thick deposits of continental to marine siliciclastic sandstone, mudstone and some limestone at center of the basin [20]. Based on geographical location, [22] divided it into the Upper, Lower and Middle Benue Trough sectors. To the southern end, the Lower Benue Trough is bounded by the Anambra Basin, whereas at the northern end, the Upper Benue Trough is bounded by the Chad Basin (Figure 1). Furthermore, The Upper Benue Trough is itself divided into two sub-basins, named the Gongola and Yola sub basins. The Benue Trough is flanked by north central Nigeria basement, eastern Nigeria basement complex, Adamawa highland and younger granite. The basin was also intruded by

Cenozoic volcanic rocks. The Basement complex of Nigeria is divided into three: Migmatite-Gneiss Complex, the Schist belts and the Older Granites [23, 24]. Geologically, the research area is comprised of three (3) main rocks groups which include; the Precambrian basement rocks, the Cretaceous sedimentary rocks, and the Cenozoic volcanics that intruded the pre-existing rocks (Figure 1) [25]. The crystalline basement rocks outcrops are porphyritic biotite - hornblende granites, medium grained biotite - hornblende granites [25].

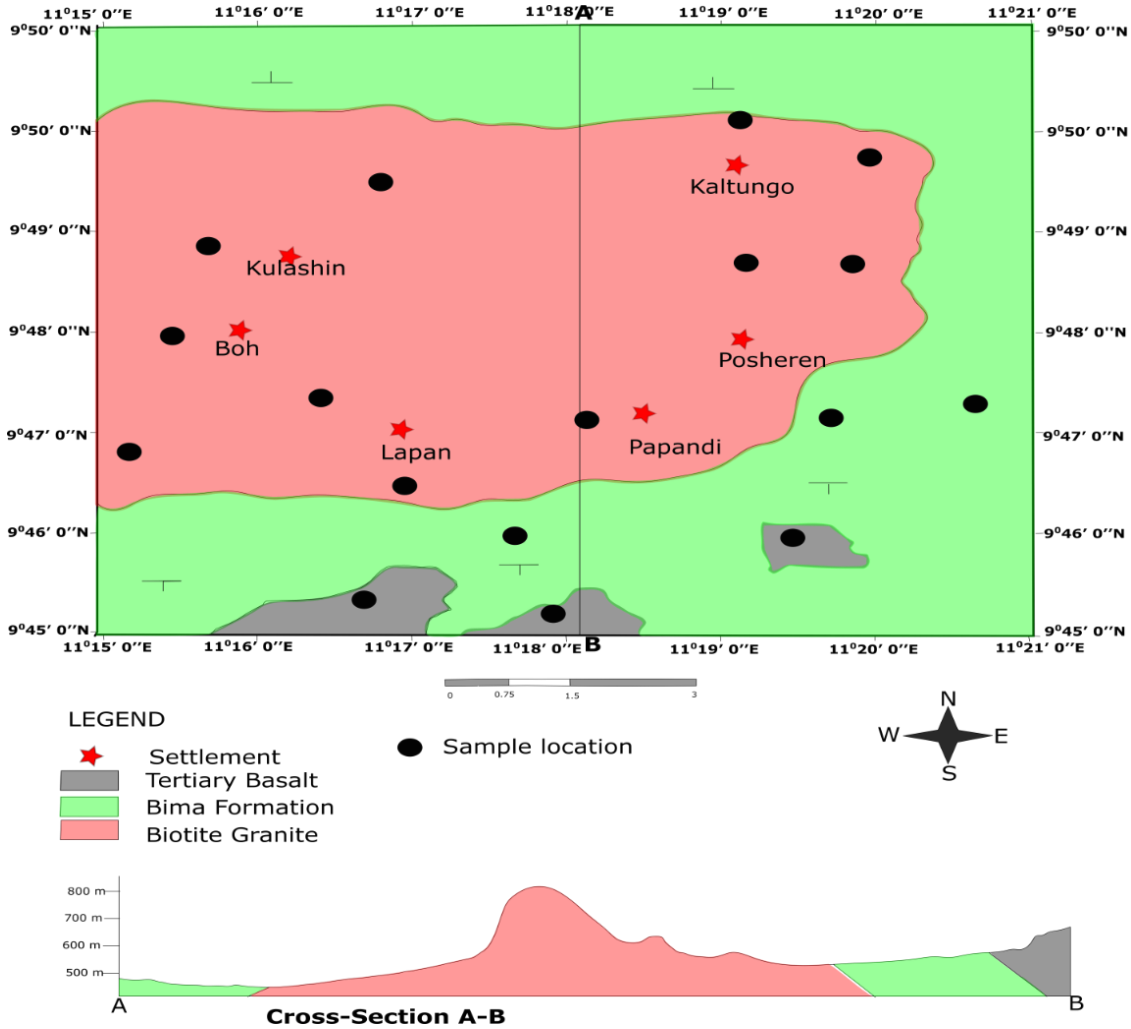

Figure 1. Geological map of Kaltungo modified from [7].

3 MATERIALS AND METHODS

3.1 Sample collection and preparation

The sample selections, distribution as well as the intensity were the key parameters reflecting the importance of the study. Thus, in locating the sampling sites, several factors such as rock types, agricultural activity, river influence and availability of wells were taken in to consideration (Figure 1). Groundwater sampling was undertaken during April, 2024, at the peak of dry season. Forty 40 water samples were sampled from bore wells, and different ions like HCO_3^-, Cl^-, SO_4^{2-}, $PO4_3^-$, NO_3^-, F^-, H_4SiO_4, Ca^{2+}, Mg^{2+}, Na^+, and K^+ were analyzed from the samples so as to cover the different rocks type within the study area. Half-liter of polyethylene bottles was used to sample the water and the bottles were rinsed three times with the very sample to be collected and also appropriately sealed and stored at standard temperature of 4°C in the laboratory for analysis [26]. Furthermore, in analyzing the samples, standard procedures of [27] has been employed to determine major cations, minor anions.

3.2 Geochemical parameters considered for study

Basically, there are nine key parameters upon which water quality for agriculture dependent. Among the key factors are sodium percentage (Na %) as reported by [28], permeability index (PI) as detailed by [29], soluble sodium percentage [30], sodium adsorption ratio (SAR) as explained by [31], Kelly's Ratio [32], potential salinity [33], exchangeable sodium percentage [34], magnesium hazard [35], and residual sodium carbonate [36]. Considering the aforesaid criteria, the following indices of irrigation water quality, like EC, Kelly's ratio, Mg^{2+}hazard, Na%, PI, PSS, SAR, RSC, SSP were outlined and considered in evaluating the suitability of groundwater quality for irrigation purposes [28, 36]. The surfer software was used for plotting the spatial distribution of all the indices in the study area. Table 1 underlines all the values for all the calculated water quality indices. Figures that followed show the maps of all irrigation water quality parameters distribution across the study area.

3.3 Derivation of irrigation water quality indices

In determining the indices of irrigation water quality for the study, the following formulas were considered:

$$\text{Residual sodium carbonate (RSC)} = (CO_3 + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (1)$$

$$\text{Kelley's Ratio (KR)} = \frac{Na^+}{Ca^{2+}+Mg^{2+}} \quad (2)$$

$$\text{Potential salinity (PS)} = Cl^- + 0.5 \times SO_4^{2-} \quad (3)$$

$$\text{Magnesium hazard (MH)} = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100 \quad (4)$$

$$\text{Soluble sodium percentage (SSP)} = \frac{Na^+}{Ca^{2+}+Mg^{2+}+Na^+} \times 100 \quad (5)$$

$$\text{Sodium percentage (Na\%)} = \frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^+ + K^+} \times 100 \quad (6)$$

$$\text{Sodium absorption ratio (SAR)} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (7)$$

$$\text{Permeability index (PI)} = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+} \times 100 \quad (8)$$

$$\text{Exchangeable sodium percentage (ESP)} = \frac{(-0.0126+0.01475\times SAR)}{1+(-0.0126+0.01475\times SAR)} \times 100 \quad (9)$$

4 RESULTS AND DISCUSSION

4.1 Descriptive statistics of water quality indicators

The results of the maximum, minimum and mean of the water quality indicators evaluated for Kaltungo area are presented in Table 1, computed irrigation indices values for all the water samples were presented in Table 2 while Table 3 represents the suitability and significance of groundwater sources based on irrigation models.

Table 1. Results of physicochemical parameters of water

Parameters	Irrigation Standards after FAO standards [37],	Max.	Min.	Mean
pH (no unit)	6-8.5	8.32	6.82	7.43
Temperature (°C)		28	24.5	25
TDS (mg/L)	0 – 2000	672	112	265
Salinity	-			
EC (µS/cm)	0–2250	1345	225	537
Cl- (mg/L)	0–1063	189	25	83
SO42-(mg/L)	0–960	32.4	1.37	14
PO4-	0–10	7.75	0.03	2.05
NO3- (mg/L)	0–10	51.5	11.53	27.5
Ca2+(mg/L)	0–60	52.47	2.47	15.87
Mg2+ (mg/L)	0–400	37.54	1.46	12.18
Hardness (mg/L)	-	342	23.5	172
Alkalinity (mg/L)	-			
HCO3- (mg/L)	0–610	78	8	30.5
CO3- (mg/L)	-	114	18	22
Na+	0–920	529.5	23.3	73.3
K+	0–1.5	46.5	1.35	12.1
Fe2+	5	13.3	0.4	3.6
F-	0–20	11.3	0.16	1.83

Table 2. Computed water samples values for all the irrigation indices selected in the study area

S/N	Water source	EC (µs/cm)	SAR	PI	SSP	Na%	RSC	MR	KI
1	First bank	359	17.68316	90.34705	89.11436	19	35.91	24	3.754734
2	Snake bite	282	9.215958	77.8665	73.91543	33	27.04	57	1.810185
3	Termana guest	225	8.09449	70.07792	67.00902	39	12.07	74	1.404819
4	Agric qtrs.	529	22.53312	84.62605	93.45137	19	6.08	56	3.873522
5	Anguwan wali	316	17.37561	92.81173	90.33404	17	29.17	68	4.390805
6	College of arabic	432	12.51263	75.31028	75.38436	31	16.19	77	1.987885
7	Lapandin-tact	653	21.73435	80.10136	94.34988	21	6	57	3.137083
8	Umar memorial school	495	16.62432	84.06323	85.77172	18	22.3	39	3.175912
9	Lakwandal	526	20.09392	85.07986	92.37185	17	3.42	60	3.85567
10	Oklong	371	10.29608	66.4462	62.2065	42	16.05	41	1.377102
11	Kalarin-ramal	763	17.8042	70.16935	74.83523	32	14.89	30	1.834218
12	Okra	594	15.40771	71.87298	73.60922	32	15.07	59	1.898573
13	Aya	926	24.47097	76.98007	90.73199	24	11.96	40	2.637546
14	Poshereng	415	22.64235	86.73586	89.39967	17	21.4	72	4.700862
15	Popandi	568	19.61823	81.62869	88.26646	22	4.08	61	3.189218
16	Lakolin	842	15.80215	66.79907	73.5172	35	9.77	52	1.592525
17	Kalargu tsohongari	262	10.28372	65.9173	67.25679	38	25.18	73	1.489924
18	Kalargu kori	545	11.85419	69.97701	71.41754	36	55	45	1.505484
19	Transformer junction	385	9.055087	54.37112	59.81535	46	19.88	49	0.963962
20	NDE office	524	13.91761	66.5226	67.43261	37	6.96	60	1.575051
21	Kulushin	432	13.18556	69.62593	77.71488	33	19	35	1.62303
22	Kulushin 2	373	8.02606	52.45025	56.62565	49	-0.02	62	0.836593
23	Kulushin- beil	261	5.606287	42.7354	45.11037	59	-25.99	43	0.59102
24	Boh	625	30.3714	92.35464	87.84038	14	26.29	28	6.275833
25	Kalbulak	418	17.26828	77.78907	95.93346	27	8.18	37	2.556091
26	Karel Poppi	739	26.93365	86.52634	89.59874	19	68.95	22	3.80519
27	Layenge	596	10.54339	51.52274	63.41113	46	-29.01	53	0.891016
28	ECW Success School	427	10.08211	63.43504	76.7168	37	-1.87	31	1.283123
29	Kalgudo	811	28.92473	85.46941	84.12917	19	42.87	48	4.001148
30	Lapan 2 PDP office	534	10.00798	55.04545	86.36658	37	-30.11	35	1.053647
31	Lapan 2 PDP office	462	15.94258	87.53062	92.4179	19	13.1	14	3.582828
32	Lapandi	458	15.20461	83.91239	80.17124	24	17.15	57	2.999222
33	Lanteme	501	25.75624	82.9162	80.17308	22	13.77	54	3.625842
34	Kale-popandi	425	20.39058	78.68622	82.88825	24	-2.11	38	2.87734
35	Kalarin kuka	694	50.20413	96.04615	101.9737	9	57.28	26	9.953616
36	Kasuwa	627	19.30229	70.20689	87.57994	29	7.96	25	1.910462
37	Baganje 1	479	17.9936	69.91831	86.45842	28	-18.91	23	1.989245
38	Baganje 2	1345	182.6371	98.39873	99.02435	4	64.19	44	31.49851
39	Nasarawo 1	563	7.680446	43.67813	83.79914	42	-48.92	18	0.679287
40	Nasarawo 2	728	2.987264	74.42973	65.08344	48	44.82	19	0.697168

Table 3. Classifications and suitability for interpretations of water quality for irrigation [38]

Parameters	References	Classifications	Irrigation Suitability	% of Samples
EC (µS/cm)	Wilcox, 1955	< 250	Excellent	3
		250–750	Good	85
		750–2250	Doubtful	12
		> 2250	Unsuitable	0
SAR (meq)	United States salinity Laboratory, 1954	<10	Excellent	18
		10–18	Good	47
		18–26	Doubtful	20
		>26	Unsuitable	15
PI (%)	Doneen, 1964	>75	Good	55
		25–75	Marginal	45
		<25	Unsuitable	0
Na%	Wilcox, 1955	0–20	Excellent	30
		20–40	Good	52
		40–60	Permissible	18
		60–80	Doubtful	0
		>80	Unsuitable	0
SPP (%)	Todd, 1959	<60	Suitable	3
		>60	Unsuitable	97
RSC(meq)	Eaton, 1950	<5	Good	25
		5–10	Doubtful	15
		>10	Unsuitable	60
MH (%)	Raghunath, 1987	<50	Suitable	60
		>50	Unsuitable	40
KR (meq)	Kelly, 1963	<1	Suitable	15
		1–2	Marginal Suitable	38
		>2	Unsuitable	47

4.2 Irrigation water quality models

4.2.1 Electrical conductivity

Electrical conductivity (EC) reflects the total ions present in the groundwater and indirectly indicates the salinity of water [39]. As previously classified by [40], in table 3, groundwater with an EC value of below 250 µS/cm is designated excellent, 250 to 750 µS/cm is considered good, between 750 to 2250 µS/cm is doubtful, and beyond 2250 µS/cm is classified as unsuitable for irrigation purposes. The results of the EC (Figure 2a, Tables 1 and 2) of all the groundwater sources in the area range from 1345 to 225 µS/cm with an average value of 537 µS/cm. Generally, the results were within the recommended values of 250–750 for excellent to good irrigation water using the classification methods adopted by [38], as 3% and 85% of the samples are rated as excellent and good respectively, whereas only 12% of the samples was interpreted as doubtful (Table 3). Therefore, a larger percentage of the groundwater sources can be categorized into good irrigation water group. Thus, the irrigation salinity threshold values of the groundwater under study is effective for growing Soya beans and other Cereal crops in the region.

4.2.2 Sodium adsorption ratio

Sodium absorption ratio (SAR) is one of the most important indicators in determining the compatibility of water for irrigation. It provides an insight on Mg^{2+}, $Ca^{2+}$and Na^{+} ions in water, thus revealing cation-exchange participation processes and the amount of irrigation water in the soil [41]. In the study area, the total SAR value range from 2.9 to 182.6, with an average value of 16.5 meq (Table 1). Approximately 18% and 47% (65%) of the samples collected in the studied area were considered excellent to good (SAR = < 18 meq), 20% were doubtful (18–26 meq), and the remaining 15% fell into the unsuitable (>26 meq) category for irrigation (Table 3). The results of the SAR (Figure 2b) of all the groundwater sources in this study were generally low, with 6 wells representing (15%) having the highest values were considered unsuitable. Generally, the results computed were within the recommended values of 0–18 for good irrigation water [38], a larger portion of all the water sources can be categorized into the good irrigation water group. Excess sodium in irrigation water produces effect on infiltration and permeability. In most cases, the sodium ion in water can replace magnesium and calcium in the soil which reduce the

tendency of the soil to form a stable aggregate and thus losing the soil structure. Additionally, high SAR in water decreases osmotic activity of the plants, absorption of water and reduced nutrients thereby reducing crop production [42].

4.2.3 Permeability Index

Permeability index (PI) is a key indicator used to determine the water movement capacity of the soil based on the concentration of Ca^{2+}, Mg^{2+}, Na^{+}, and HCO_3^{-}. [43], divided irrigation water into three classes depending on the PI: Class I (more than 75%; excellent water), Class II (25%–75%; acceptable water), and Class III (up to 25%). In the research area, the PI values of all water sources (Figure 2c) are high and suitable for irrigation based on this classification. The cations (Ca^{2+}, Na+, and Mg^{2+}) and HCO_3^{-} determined the PI of any water. High PI value indicates high sodium and bicarbonate in the water sample and in most cases is as a result of dissolution of carbonate in dolomite and calcite rocks. However, water with a low PI does not pose a threat to the surrounding soil since it does not change the permeability of the surrounding soil [44].

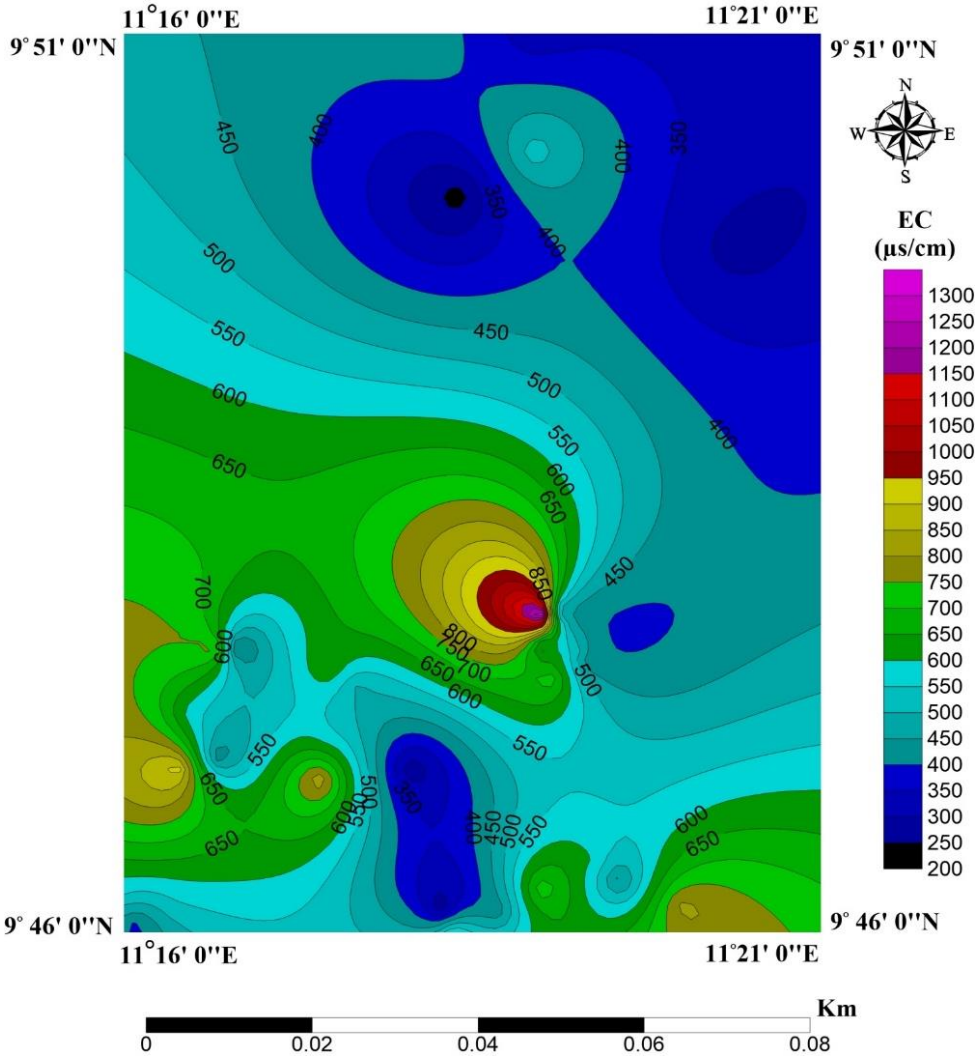

Figure 2a. Spatial distribution of EC in the study area

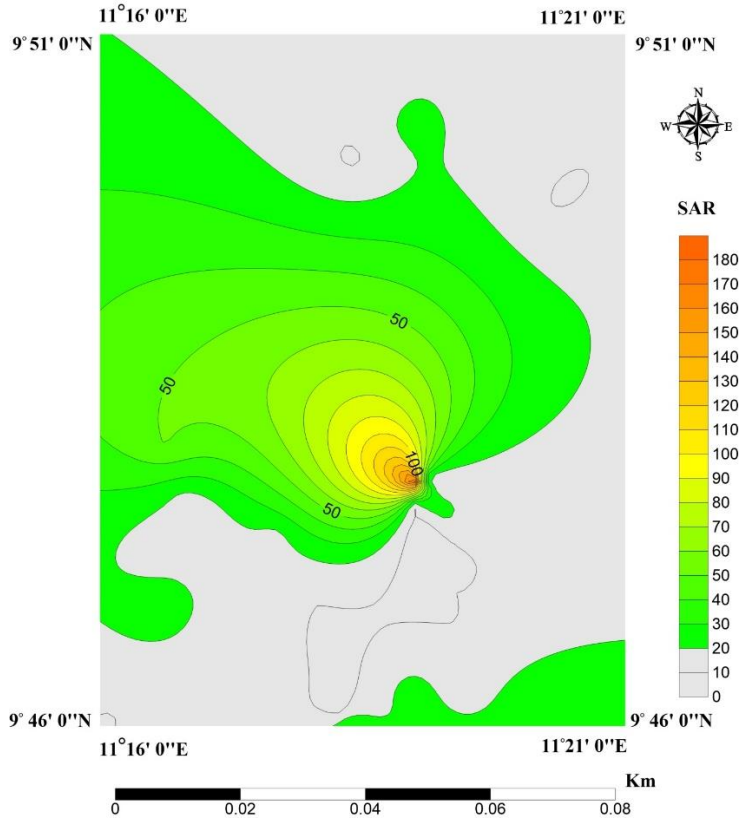

Figure 2b. Spatial distribution of SAR in the study area

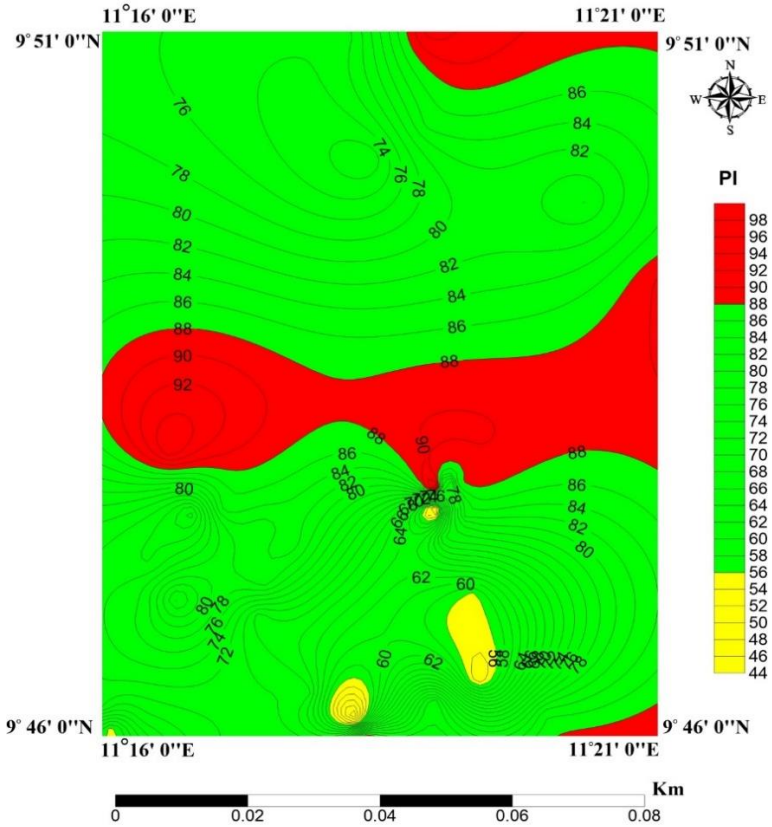

Figure 2C. Spatial distribution of PI in the study area

4.2.4 Sodium percentage or sodium hazard

Sodium percentage (%Na) also known as sodium hazard is one of the major indices that drives the suitability of groundwater for irrigation. [45] Explained that higher concentration of Na^+ ions in water create chemical bonding with soil by reducing soil permeability and soil structure and thus leading to stunted plants growth. Furthermore, higher Na^+ in irrigation water with respect to other cations, and low salinity reduces the infiltration capacity of the soil. Using [40], method for the calculation of sodium hazard (Table 3), 30% of the groundwater sources evaluated here are excellent for irrigation, 52% are good for irrigation, 18% are permissible for irrigation Figure 2d.

4.2.5 Soluble Sodium Percentage

The Soluble sodium percentage (SSP) is an important parameter for assessing irrigation water according to soil permeability [46]. Groundwater containing SSP levels less than 60 is regarded as good for irrigation (Table 3), whereas when the SSP value is above 60, then is considered unsuitable for irrigation [47]. In the groundwater samples analyzed, the SSP value range of 45 to 101 (Table 3). Furthermore, majority of the samples which represent 97% were considered unsuitable for irrigation, while only 3% which represent only 1 sample is classified as suitable for irrigation (Table 3) (Figure 2e).

4.2.6 Residual Sodium Carbonate

Residual sodium carbonate (RSC) concentration computed in the study area ranges from − 48.9 to 69.9 meq, with an average of 7.9 meq (Table 1).For residual sodium carbonate, three classes were established: good (< 5 meq), doubtful (5–10 meq), and unsuitable (>10 meq) (Table 2). However, 60% of samples are judged unsuitable, while 15% are doubtful and 25% are deemed good quality for irrigation (Table 3). Spatial distribution map of RSC showing good, doubtful and unsuitable has been depicted (Figure 2f).

4.2.7 Magnesium hazard

Magnesium ion is a key nutrient that drives growth of crop and is one of the driving forces behind photosynthesis in plants. Based on the result of the calculated MH, about 60% of the water samples are suitable for irrigation purposes whereas the remaining 40% are unsuitable (Table 3). According to [48], higher values of magnesium hazard (MH) >50 in groundwater have the tendency to render the soil alkaline, thus reducing the crop yield. The soil fertility will be degraded over time when the water with higher magnesium hazard is continued to be applied on the soil [49, 50]. Higher MH values >50 was observed as distinct zones on the extreme north, east and southern regions as patches, whereas values <50 were observed in central and the western region of the study area (Figure 2g). The groundwater quality could be said to be generally suitable for irrigation, with 60% shows suitability and 40% representing unsuitable for irrigation purposes. However, [51] further established that increased in Mg ion concentrations, specifically when combined with Ca^{2+}, can elevate pH of the soil, which reduces phosphorus availability and, in turn, lowers crop output.

4.2.8 Kelly ratio (KR)

The magnitude of the KR value is largely determined the suitability of groundwater for irrigation purposes. Additionally, KR is a key important index that assessed irrigation suitability of groundwater based on the concentration of Na^+ against $Ca^{2+}$and Mg^{2+} [32, 52]. Other workers further explained that the Mg^{2+}content in soil have the tendency to enhance the alkalinity to the soil, which can reduce the crop yield. Groundwater sources with KR values above two (2) (Table 3) Figure 2h is often considered unsuitable [53]. The result computed from this study reveals that 53% of the water samples have a KR value less than 2 and is considered suitable for irrigation purposes, whereas the remaining 47% representing 19 samples are unsuitable.

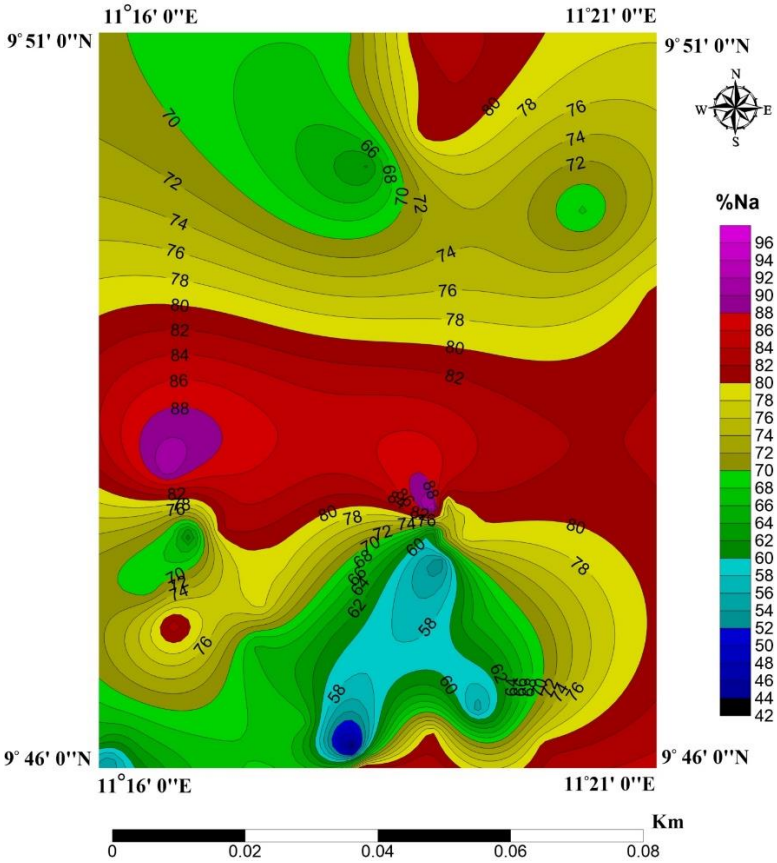

Figure 2d. Spatial distribution of %Na in the study area

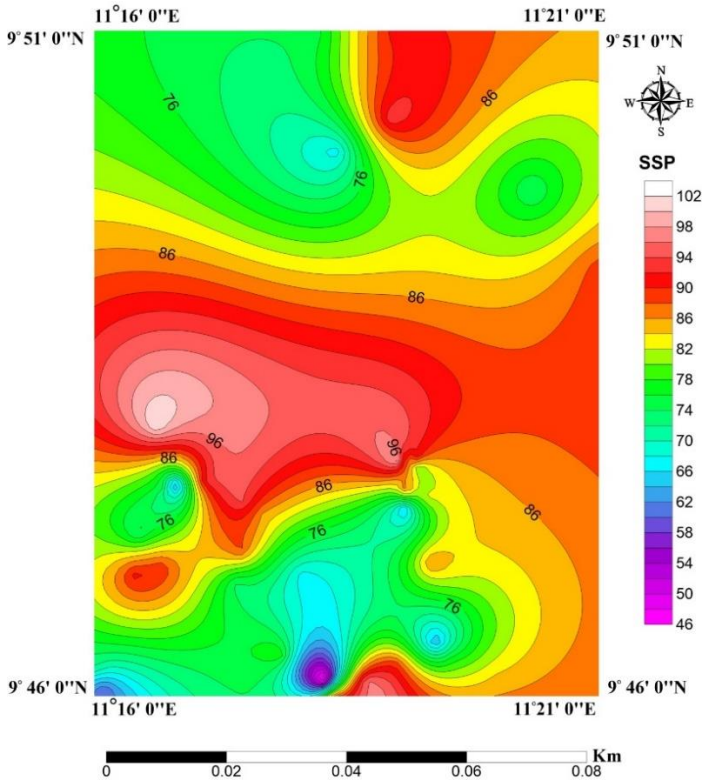

Figure 2e. Spatial distribution of SSP in the study area

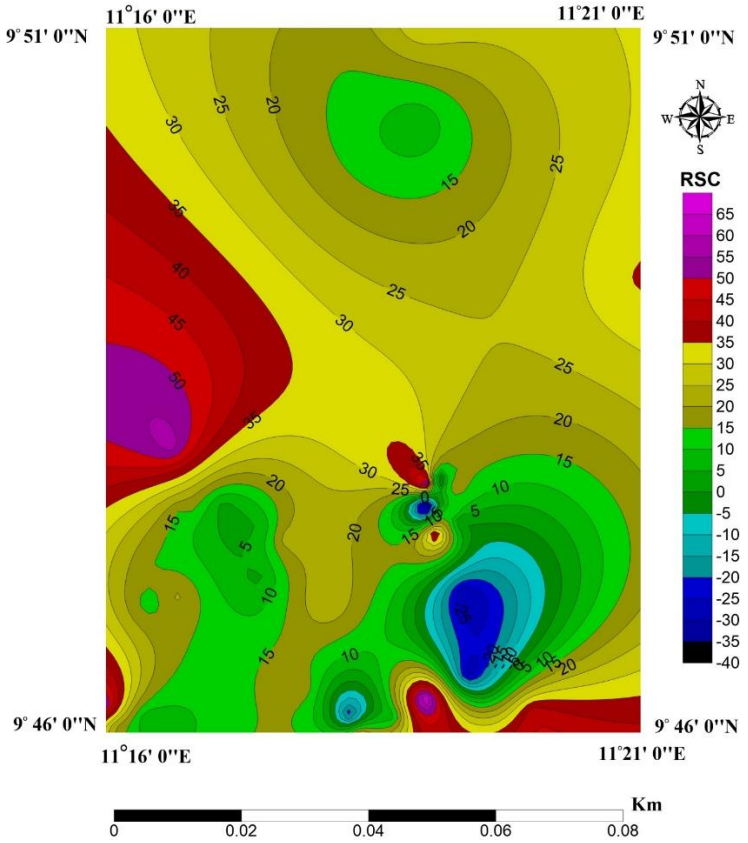

Figure 2f. Spatial distribution of RSC in the study area

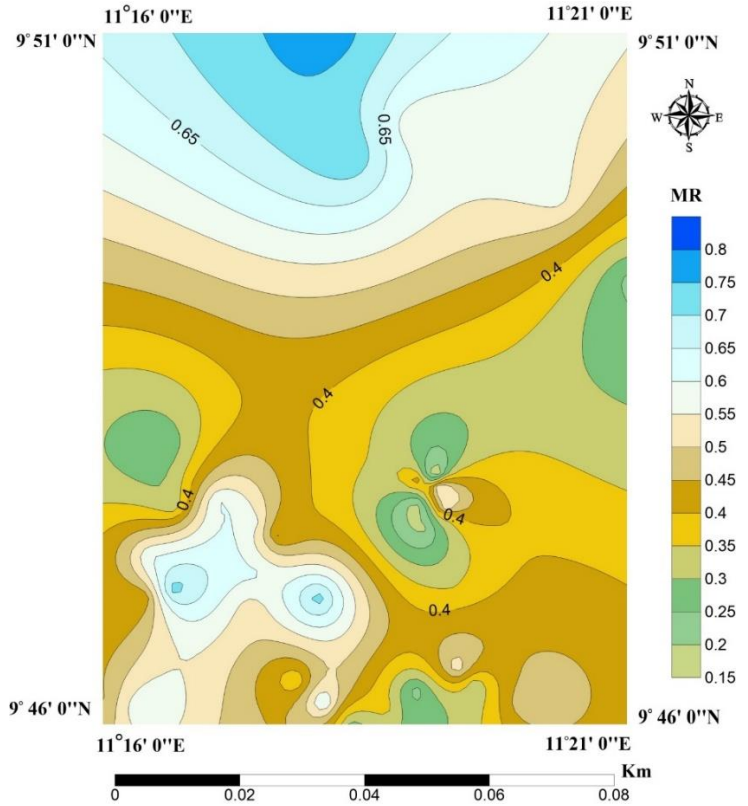

Figure 2g. Spatial distribution of MR in the study area

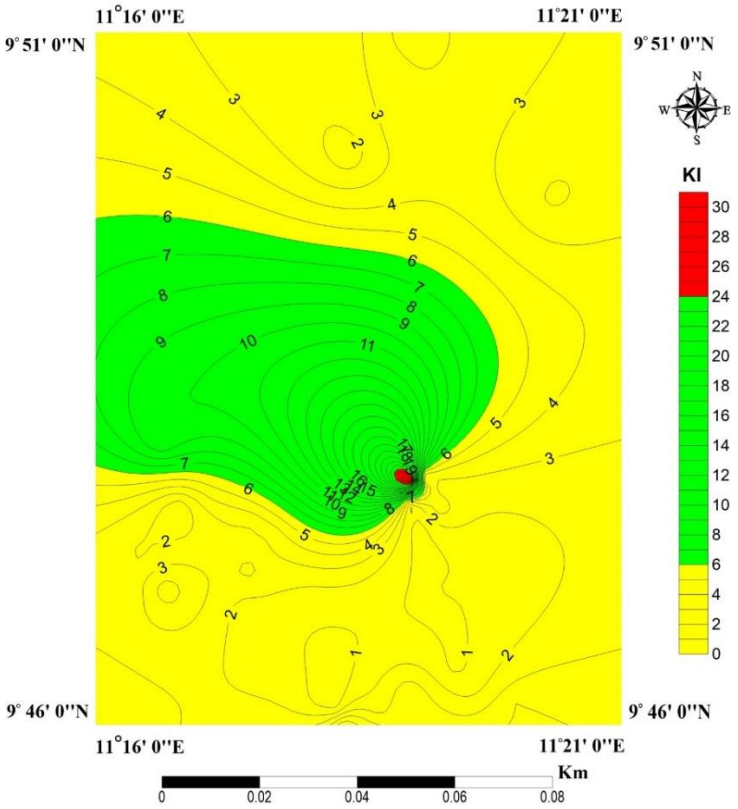

Figure 2h. Spatial distribution of KI in the study area

5 CONCLUSIONS

The irrigation suitability of groundwater resources in the study area has been investigated. The physicochemical analysis showed that the groundwater samples were within the permissible limits except for Ca^{2+} and K^{+} which were a little above the limits in a few cases; hence the irrigation indices values calculated revealed excellent to good water for irrigation purposes. When compares to reference values; Kelly ratio (KR), Residual sodium carbonate (RSC) and Soluble sodium percentage revealed that some groundwater sources may not be suitable for use as irrigation water. Generally, the groundwater in the study area is suitable for irrigation, but the sustainability of all these groundwater sources based on quality should be investigated.

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