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SUITABILITY OF WATER FROM THE CONTINENTAL TERMINAL OF SOKOTO BASIN IN NORTH WESTERN NIGERIA FOR IRRIGATION

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Abstract

Physico-chemical parameters of water are major factors limiting optimum agricultural yield in irrigated agriculture especially practiced in arid and semi-arid areas like Sokoto Basin, Nigeria. Some vital quality parameters of the groundwater of Gwandu Formation a Continental Terminal of Sokoto Basin were evaluated for the criteria of irrigation water suitability. Twenty eight water samples were collected from existing wells in July 2013 and April 2014 from different locations in Gwandu Formation (Eocene) covering Sokoto, Kebbi and Zamfara States, which constitutes Sokoto Basin and were subjected to physicochemical analyses.The physicochemical analysis conducted on the representative water samples of Gwandu Formation were in accordance with standard procedure. The electrical conductivity (EC) value of water of the study area ranges from 10.9 to 760.0µS/cm (mean =164.93µS/cm). The total dissolved solid (TDS) values range from 0.00 to 536.63ppm (mean= 116.08ppm). The studyrevealed thatEC,and TDS, evaluated were suitable for irrigation. Besides, the results realized from advance assessment and evaluation of physicochemical parameters for Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR),and Soluble Sodium Percentage (SSP), water quality variables, were found within the permissible limits for irrigation purposes. The RSC value obtained varies from -1.73 to 1.12meq/L (mean= -0.21meq/L), while the values of SAR of the water samples range from 0.02 to 1.82meq/L with an average value of 0.45meq/L, and SSP values were found to vary from 5.34 to 75.1% with a mean of 34.14%. Ground water development of Gwandu Formation, the Continental Terminal of Sokoto Basin via planned irrigation projectsis therefore recommended.

Key Words: Nigeria, Irrigation, and Physico-Chemical Water Parameters

1. Introduction

Irrigated agriculture often depends on adequate water supply of suitable quality which is not necessarily closely monitored or regulated. Increasing demand for the use of limited water supplies has been the reason for some irrigators to consider using water previously thought to be of only marginal quality for irrigation, (Bauder *et al*., 2008). Water quality for irrigation purpose may be related to its effects on soils, crops and its management. Though better quality crops can be produced only by using monitored, regulated water which is suitable for irrigated agriculture while keeping other inputs optimal. The quality and quantities of the water used on irrigated agriculture are as variable as the environmental and geo-logical characteristics (Yidana*et al*., 2011; Chemura *et al*., 2014). The characteristics of irrigation water that define its quality as stated by Islam *et al*., (2009) vary with the source of the water. For instance, the differences in the quality of water available on a local level depends on whether the source is from surface water bodies (rivers and ponds) or from groundwater aquifers with varying geology; and whether the water has been chemically treated.

The variation in water quantity is directly related to productivity in irrigation schemes in the short term while variations in terms of water quality affect productivity in the long term (Ayers *et al*., 1985), (Mujere *et al*., 2011).The chemical composition of irrigation water can affect plant growth directly or indirectly through toxicity or deficiency (Ayers and Westcot, 1985; Rowe *and Abdel-Magid.,* 1995). The physico-chemical parameters of irrigation water of significant consideration include the Total dissolved solids (TDS), conductivity, pH, temperature, the major cations and anions concentrations (Na,Mg, K, Ca, HCO_3, Cl, CO_3, NO_3, SO_4), constituting macro- and micro-nutrients, trace elements and heavy metals. In irrigated agriculture, the salinity hazard is a constant threat. Salts originate from dissolution or weathering of rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals. These substances are transported along with the water (UCCC, 1974; Tanji, 1990).

The knowledge of irrigation water quality enhances proper decision on choice of fertilizer, adequate quantity to apply and where to apply for optimum quality crop yield. More so, untreated waste-water from industries often disposed into surface water that finds its way to reservoirs for irrigated agriculture need to be considered in design of irrigation projects. This can be tackled by conducting environmental impact assessment for irrigation projects in which the water quality for the irrigation purpose has to be ascertained.

In semi-arid regions like the Sokoto Basin, irrigation using shallow wash bores and tube wells is increasing because it is internationally accepted as environment-friendly and more cost effective than the use of surface water. An investigation of suitability of water quality for irrigated crops is yet to be completely carried out in the area. As such this present study surveys suitability of water quality of Continental Terminal of Sokoto Basin (Gwandu Formation) for Irrigation purpose.

2. Study Area

Sokoto Basin as part of Iullemmeden basin is located in Northwestern Nigeria within the Latitude of $8^{0}35^{'}0''$N and $14^{0}0^{'}0^{''}$N and Longitude $3^{0}5^{'}0^{''}$E and $8^{0}30^{'}0^{''}$E covering Sokoto, Kebbi , Zamfara States and part of Kastina State with a population (according to Sokona et al., (2008)) of approximately six million. It covers a zone that has been affected by drought in the last several years due partly to climate variability and poor-quality irrigation water. The Sokoto Basin water resources is categorized into surface water, precipitation and ground water, with Sokoto and Rima Rivers as the major tributary flowing across the aquifers, draining into the river Niger and ultimately into the Atlantic Ocean.

2.1 Location, Geography, and Morphology

The study area falls within latitude 8°35'0?N to 4°0'0?N and longitude 3°5'00?E to 8°30'00?E, (Ette et al., 2017). The study area, Gwandu Formation of Sokoto Sedimentary Basin cuts across Sokoto, kebbi, and Zamfra States in the north western section of the Northern Region in Nigeria. The Gwandu Formation unconformably overlies the Kalambaina in the northern and central parts of the Sokoto Basin and Southward, where it overlaps Kalambaina it rest directly on the Rima and Illo Group.

2.2 Geology, Hydrogeology and Climatic Features

The hydrogeological setting of Sokoto basin is such that the aquifer system has about 60 000km^2 of Iullemedem aquifer system and is multilayered including Continental Intercalaire at the bottom (Gundumi-Ilo Formation) overlain by three layers of Continental Terminal consisting of Rima Group, Sokoto Group and Gwandu Formation. Gwandu Formation (Eocene) out crops in over 8 500 square miles in the western third of the Sokoto Basin and it consists of the sediments of terrestrial origin that are made up of interbedded semi-consolidated sand and clay. The Gwandu aquifer is recharged principally by infiltration from precipitation and from runoff on the outcrop area, (Anderson et al., 1973). The basin has two season climate- dry and rain.

3. Materials and Methods

The approach adopted in realizing the main aim of this study include: systematic approach involving desk study, field measurement and sampling campaigns, laboratory analysis, and results presentation and interpretation were applied to evaluate the suitability of water from Gwandu Formation- the Continental Terminal of Sokoto Basin for irrigated agriculture.

The desk study included collection and study of existing documents in line with irrigated agriculture and the study area. Field measurements and sampling consist of in-situ measurement of physical water parameters such as the total dissolved solid (TDS) and electrical conductivity (EC) measurement using Martini combined meter kit as well as collection of ground water samples from existing wells using 500mL high density polyethylene (HDPE) containers each for anions and for cations. Those for cation were acidified with nitric acid to avoid precipitation of substances like calcium. Samples locations were properly geo referenced using Garmin 72H model global positioning system (GPS) (Ette*et al*.,2017). Samples were collected in July 2013 and April 2014 in collaboration with Nigeria Hydrological Services Agency (NIHSA) following International Atomic Energy Agency(IAEA) recommended procedures. A total of 26 water samples from Gwandu Formation were collected from various states constituting the Sokoto basin. The analysis for the physico-chemical parameters of the samples were carried out following the standard analytical methods. Na^+ and K^+ were determined by flame photometry as in Jackson, (1967); Ca^{2+}, Mg^{2+}, by atomic absorption spectrophotometry (Jackson, 1967 and Page *et al.,* 1982); $C1^-$ and HCO^-_3 by titration method (Jackson, 1967).The concentrations of ions measured in mg/L were converted to meq/L to ease reaction error calculation. The reaction error was used asa reproducibility factor. As such; the reaction error within ±10% was acceptable for measured ions. The variables such as sodium adsorption ratio (SAR) were estimated from the equation. (1), (Richards, 1954):

$$SAR = \frac{Na^+}{\sqrt{(Ca^{+2}+Mg^{+2})|2)}} \qquad (1)$$

Using the values obtained for, Ca^{2+}, Mg^{2+} in meq/I; the soluble sodium percentage (SSP) was determined from the equation. (2), (Todd, 1980):

$$SSP = \frac{Na100}{Ca + Mg + Na + K} \qquad (2)$$

Using the values obtained for Na^+, K^+, Ca^{2+}, Mg^{2+} in meq/l; and the residual sodium carbonate (RSC) was determined from the equation.(3), (Eaton, 1950) expressed as:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \qquad (3)$$

All ions are expressed in meq/l. These advance calculations made from physicochemical parametersof water samples were applied in this context to evaluate suitability of waters of Gwandu Formation for irrigation purposes.

4. Results and Discussion

Data presented in Table 1 represent the results of variables of the irrigation water samples of the Continental Terminal-Gwandu Formation of Sokoto Basin, while data presented in Table 2 show the suitability status of the variables of water quality for irrigation purposes.

Table 1: Evaluated variables of water quality for irrigation purpose

Location ID	Stn ID	RSC (meq/L)	SAR(meq/l)	MH(meq/l)	TDS (mg/L)	SSP(%)	EC (uS/cm)
Silame	GWSS64	-0.11	0.4	12.47	48.23	38.27	100
Ganbuwa	GWSS78	-1.73	0.47	19.7	536.63	16.42	760
Binji	GWSS2	0.03	0.37	37.96	0	46.22	53
GidanMadi	GWSS3	-0.69	1.82	32.54	220	65.63	324
Tangaza	GWSS4	0.01	0.15	39.3	0	41.36	40
Balle	GWSS5	-0.14	0.23	71.46	80	20.89	127
Rundi	GWSS31	-0.37	0.54	23.39	90	33.99	136
Yabo	GWSS34	-0.07	0.69	40.96	30	57.2	49.5
Shagari (GDSS)	GWSS35	-0.66	0.27	10.9	100	19.97	153
Gwandu	GWSS36	0.05	0.61	31.42	0	71.69	10.9
Tambuwal	GWSS37	0.43	0.77	13.92	310	31.01	455
Kalgo Police Barrack	GWSS39	0.02	0.42	38.21	10	75.1	15.7
BirninKebbi	GWSS40	0.16	0.41	50.7	180	23.02	270
Goru	GWSS41	-0.15	0.75	37.95	60	56.17	98
Alwasa	GWSS44	0.04	0.29	41.86	50	35.29	81
DageriPri. Sch	GWSS43	-0.54	0.22	38.96	80	31.46	120
TunganIsiaka	GWSS45	1.12	1.21	55.14	170	49.39	265
Tambuwal	GWSS57	-0.21	0.31	14.38	70	22.4	120
Sanyinna	GWSS58	-0.55	0.18	24.45	121.01	15.28	170
Tiggi	GWSS59	-0.15	0.1	48.8	50	14.56	90
Argungu	GWSS60	-0.33	0.09	49.05	100	13.07	160
BirninKebbi	GWSS61	0.01	0.43	49.03	150	24.78	230
Kalgo	GWSS62	-0.3	0.22	35.12	40	27.1	70
katami	GWSS63	-0.2	0.02	30.33	70	10.57	110
Salah	GWSS75	-0.73	0.46	21.91	20	26.9	40
Gundun	GWSS76	-1.53	0.12	20.12	230	5.34	360
Min		-1.73	0.02	10.9	0	5.34	10.9
Max		1.12	1.82	71.46	536.63	75.1	760
Mean		-0.21	0.45	34.18	116.08	34.14	164.93

Abbreviation defined: Stn- station, RSC-residual sodium carbonate, SAR-sodium absorption ratio, MH-Magnesium hazard, TDS- total dissolved solid, SSP-soluble sodium percentage, Temp-Temperature, Cond-Conductivity, GWSS-ground water sampled station, SRIS- Surface water samples station.

Table 2: Suitability conditions of water quality for irrigation purpose

Stn ID	RSC (meq/L)	SAR(meq/l)	TDS (mg/L)	EC.(uS/cm)
GWSS64	S	S	E	E
GWSS78	S	S	G	G
GWSS2	S	S	E	E
GWSS3	S	S	E	E
GWSS4	S	S	E	E
GWSS5	S	S	E	E
GWSS31	S	S	E	E
GWSS34	S	S	E	E
GWSS35	S	S	E	E
GWSS36	S	S	E	E
GWSS37	S	S	E	E
GWSS39	S	S	E	E
GWSS40	S	S	E	E
GWSS41	S	S	E	E
GWSS44	S	S	E	E
GWSS43	S	S	E	E
GWSS45	S	S	E	E
GWSS57	S	S	E	E
GWSS58	S	S	E	E
GWSS59	S	S	E	E
GWSS60	S	S	E	E
GWSS61	S	S	E	E
GWSS 62	S	S	E	E
GWSS63	S	S	E	E
GWSS75	S	S	E	E
GWSS76	S	S	E	E

Abbreviation defined: S=Safe, E= Excellent, G= Good, SAR= Sodium absorption ratio, RSC= Residual sodium carbon

4.1 Salinity

Table 1 reveals that the EC value of water of the study area ranges from 10.90 to 760 µS/cm with an average value of 164.93 µS/cm. The pre stated range value of EC, according to Wilcox (1955) falls within the irrigation water quality classification of 'excellent to good'. Besides, electrical conductivity may also be classified based on the 'degree of restriction on use' following (UCCC, 1974) EC classification for irrigation. EC value < 700 µS/cm refers to the water that may be useful for any purpose, it also implies that it has 'none' restriction on further utility of the water; This classification suggest that water from Gwandu Formation may be utilized for irrigation and other agricultural purpose like animal rearing. For instance Livestocks according to (Mazor, 2004) can take water with EC <3000µS/cm. It is presumable that with respect to the EC value, the water of the study area is suitable for irrigation purpose as it falls under category 'none' as classified in UCCC (1974), which implies that it is suitable for irrigation. The TDS values range from 0.00 to 536.63 mg/L (mean=116.08mg/L).On the average, the waters of the Formation are suitable for irrigation purpose compared with the maximium specification limit of up to 3000mg/L according to David and De Wiest (1966). In terms of 'Degree of restrictions on use', the TDS concentration within the values <450, 450-2000 and > 2000mg/L represent 'none, slightly moderate and severe' water quality for the irrigation purpose in terms of TDS, (UCCC,1974). The water quality of Gwandu Formation is suitable for irrigation purpose with respect to TDS classification.EC and TDS values of groundwater are interrelated with correlation coefficient (r) =0.999 and n=23 (Fig 1). Both values are indicative of saline water in absence of non-ionic dissolved constituents (Michael, 1992).Also, when the value of EC and TDS are considered, the classification of the water samples of the study area comes under “excellent to good” (Wilcox, 1955). In the study area, EC and TDS classification each was noted to fall in the ratio of 99 to 1 percent according to excellent to good class.

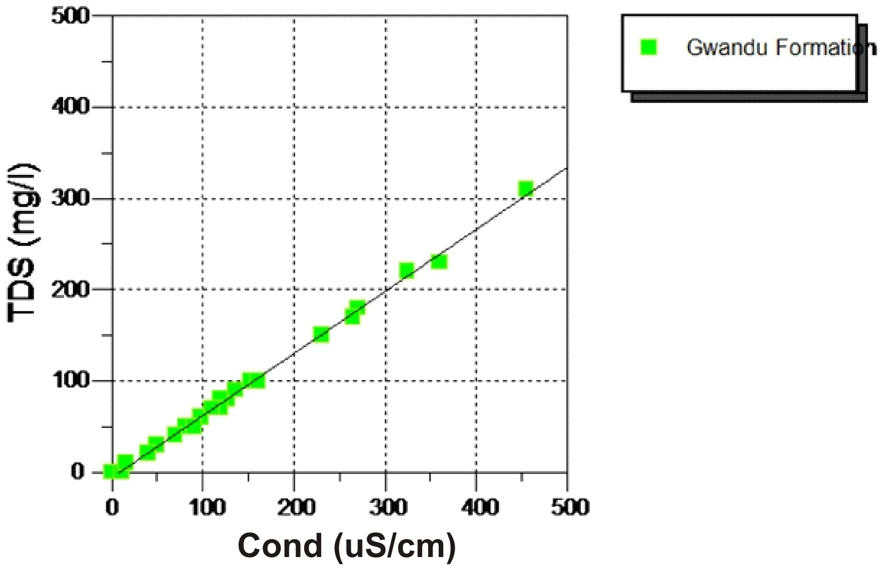

Figure 1: Plot of TDS versus EC of Gwandu Formation

4.2 Sodium Hazard

Irrigation water that has high sodium (Na^+) content can bring about a displacement of exchangeable cations Ca^{2+} and Mg^{2+} from the clay minerals of the soil, followed by the replacement of the cations by sodium. According to (Nahida, 2012), RSC signifies the amount of sodium carbonate and sodium bicarbonate in water when total carbonate and bicarbonate levels exceed total amount of calcium and magnesium. The RSC value obtained varies from -1.73 to 1.12meq/l with a mean of -0.21 meq/l. Residual carbonate levels less than 1.25meq/l are considered safe. In view of the later fact, the waters of Continental Terminal-Gwandu Formation are suitable for irrigation. Waters with RSC of 1.25-2.50 meq/l are within the marginal range. These waters should be used with good irrigation management techniques. RSC values of 2.50 meq/l or greater are considered to be too high, making the water unsuitable for irrigation. High SAR in any water for irrigation use implies a hazard of sodium (alkali) replacing Ca and Mg of the soil through cation exchange process, a situation which eventually affects soil structure (mainly permeability) which ultimately affects the fertility status of the water and reduces crop yield (Gupta, 2005). The values of SAR of the water samples range from 0.02 to 1.82meq/L with an average value of 0.45meq/L (Table 1). Table 2 shows that waters of the Continental Terminal of Gwandu Formation have SAR within the acceptable range for irrigation.

4.3 *Magnesium Hazard (MH)*

In 1964, a magnesium hazard classification system for assessing the suitability of water quality for irrigation purpose was proposed by Szaboles and Darab, (1964) since then it has been widely applied in irrigation assessment studies. It is such that, if MH exceeds 50meq/L, such water is considered to be harmful and hence is unsuitable for irrigation (Khodapanah *et al*., 2009). In this study, the mean MH recorded is 34.18meq/L. MH exceeds 50meq/L in 3 of the water samples with locations (GWSS: 5, 40, and 45) and hence are not suitable for irrigation purpose. The remaining 23 water samples has MH less than 50meq/L and hence are suitable for irrigation purpose.

4.4 Salinity and Sodium

Also, salinity classification was done using a quality diagram (Figure. 2) given by the U. S. Salinity Laboratory (Richards, 1954).

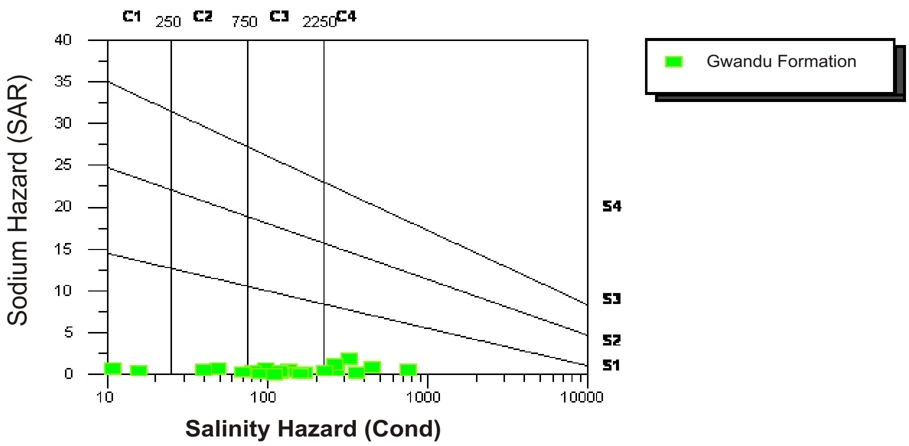

Figure 2: Salinity classification of irrigation water samples of Gwandu Formation.

The diagram classifies 16 classes, with reference to SAR as an index of sodium hazard and EC as an index of salinity hazard (Mirsha and Ahmed, 1987; Michael, 1992, Miller et al., 2007). By plotting the obtained results in the diagram (Fig. 2), it was found that the irrigation water samples, of Gwandu Formation categorizes into “C_1-S_1”, C_2-$S_{1,}$ C_3-$S_1$and “C_4-S_1” class. Such waters can be used safely for irrigation, (Richards, 1954). According to the quality diagram of Richards, (1954), water samples within class C_4 which indicates “very high salinity” at salinity hazard value of 2250µS/cm. A detailed examination of the diagram reveals that none of the water samples have such value. Hence, they fall under high salinity class. It then implies that under good agricultural practice, the crops irrigated with such water will yield optimum results. The soluble sodium percentage (SSP) values were found to vary from 5.34 to 75.1% with an average value of 34.14 % (Table 1). Based on the classification of Wilcox (1955) for soluble sodium percentage, three water samples fell under “Excellent class” and 23 samples fell under “Good” class.

Conclusions

The physico-chemical properties of water of Gwandu Formation were assessed for its suitability for irrigation. Electrical Conductivity (EC) and Total dissolved solid (TDS) of collected water samples suitable for irrigation purpose, considering that waters of the Formation were categorized between 'Excellent and 'Good' class using standard procedure. Besides, assessing the waters of the Formation for irrigation purpose using SAR, RSC , SSP and MH suggests that the waters ofGwandu Formation are safe to be used for irrigation.It is recommended that Irrigation water quality in the other Formations in Sokoto Basin needs to be assessed.

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