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Groundwater Quality Assessment for Irrigation Purposes: A case study of Minna, Niger State, Northcentral Nigeria

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Abstract

The groundwater quality in Minna, Niger State, North-central Nigeria was assessed for irrigational purposes. Fifty groundwater samples were collected and analyzed for major cations and anions. Prior to this, physical parameters such as pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were determined insitu using standard equipment. The laboratory results of the major ions were converted to either meq/l or % and used to evaluate the suitability of groundwater systems in Minna for irrigation using Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Soluble Sodium Percentage (SSP), Residual Sodium Bicarbornate (RSBC), Permeability Index (PI) and Kelly's Ratio (KR) concepts. The concentration of pH varied from 6.49 to 7.25 with an average value of 6.87. The TDS value ranged from 38.10 mg/l to 258.40 mg/l with a mean value of 67.85 mg/l. The value of EC is in the order of 75.50 µs/cm^3 to 420.20 20 µs/cm^3 and an average value of 111.30 µs/cm^3. The concentration of these physical parameters fell within the permissible limit of 6.50-8-50 for pH, 500.00 mg/l for TDS and 1000.00 µs/cm^3 for EC postulated by World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). The value of SAR ranged between 0.00 to 2.19 with a mean value of 0.35 while the value of MAR varied from 12.21 % to 74.29 % with an average value of 32.05 %. The value of SSP ranged from 4.48 % to 75.22 % with a mean value of 40.46 % while RSBC values varied from -0.95 meq/l to 2.55 meq/l with an average value of 0.25 meq/l. The value of PI varied between 35.61 % to 388.86 % with a mean value of 108.19 % while the value of KR ranged from 0.00 meq/l to 2.45 meq/l with an average value of 0.43 meq/l. The value of the computed irrigation indices when compared with some known standards revealed that the groundwater systems from the study area can be exploited and used as irrigation water without any negative impact on the soil and the crop.

Keywords: **Evaluation, Groundwater Quality, Irrigation, Minna, Niger State**

Introduction

In the last two decades, increase in commercial agriculture with the associated socio-economic impacts has led to changes in land use, resulting to high demand of water for irrigation. Interestingly, Water quality depends on a number of factors such as the local geology, degree of weathering, prevalent climatic conditions, groundwater migration pathway and resident time as well as the anthropogenic activities domiciled in the area [1, 2]. Various soil and water quality indices and parameters are now being used to ascertain the quality of water leading to the determination of its suitability for domestic, irrigational or industrial purposes. Water is an important life sustaining substance to both plants and animals. Most of the ill-health that affect plants and animals are water related, hence the need to evaluate the water quality either for domestic and or irrigational purposes cannot be overemphasized [3, 4, 5].

Water is an essential requirement of agricultural development and the most delicate part of the environment and monitoring of its quality is essential to guarantee a safe environment and high crop yield. It is a universal solvent and has the ability to dissolve and interact with organic and inorganic components of the soil material in which plants rely upon for survival. These materials constitute the amount of total dissolved solids present in the groundwater which enhances its conductivity as well as availability to plants [6]. This implies that groundwater chemistry is a function of the mineral composition, texture and structure of the soil. Soil-water interaction through which plants derived their nutrients depends largely on the water chemistry, mineralogy of the soil and residence time of the groundwater [7, 8]. The present study evaluates the suitability of groundwater systems in Minna, Niger State, Northcentral Nigeria for irrigational purposes.

Materials and Methods

Study Area Description

Minna, the Capital of Niger State, North-central Nigeria lies between latitude 9°24′ N to 9°43′ N and longitude 6°25′ E to 6°45′ E. Minna is accessible through Suleja, Bida, Gwada and Zungeru roads. The study area has good road network and drainage system. The area falls within the guinea savannah vegetation comprising various species of shrubs and high forest trees along the river channels [9, 10]. The study area is drained by River Chanchaga and its tributaries. Minna and environs is underlain by rocks belonging to the Basement Complex, which comprises of Gneiss, Schist, Granite with quartz intrusion.

Sample Collection and Laboratory Analysis

A total of 50 groundwater samples (Fig. 1) were collected in acid-washed polyethylene 500 ml bottle. The bottle was completely filled with water taking care that no air bubble was trapped within the water sample. In order to prevent evaporation, the bottles were sealed with double plastic caps and precautions were taken to avoid sample agitation during transfer to the laboratory. The samples were placed in a cooler and immediately transferred to the laboratory for analysis [13, 14]. Samples were analyzed in the laboratory for the major ionic concentrations employing standard methods [14]. Calcium and magnesium were determined titrimetrically using standard EDTA, chloride by standard $AgNO_3$ titration, bicarbonate by titration with HCl while sodium and potassium were determined through flame photometry. The samples were analyzed at the Federal Ministry of Water Resources, Quality Laboratory Minna, Niger State.

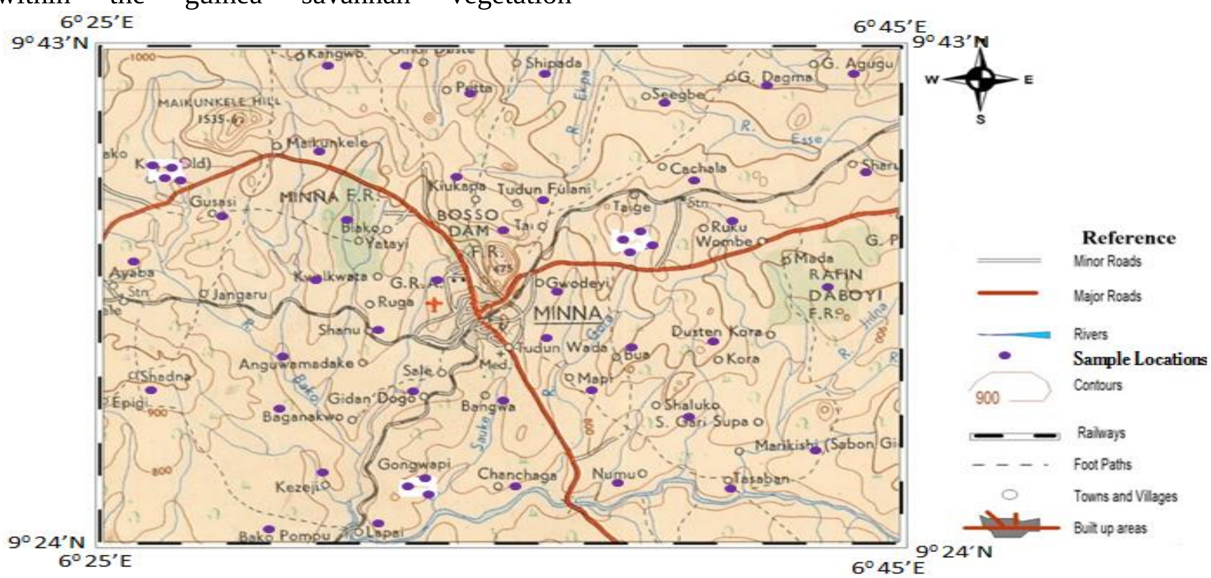

Fig. 1: Map of Minna showing the sample locations

Results and Discussion

Electrical conductivity (EC) of water is the ability of water to conduct electrical current and it is a function of the amount of dissolved solids in water. The EC is a useful parameter in categorizing salinity hazard as well as suitability of water for irrigation purposes. The conductivity values varied from 75.50 µs/cm to 420.70 µs/cm with an average value of 115.30 µs/cm (Table 1). Water with high EC leads to formation of saline soil, high sodium in water leads to development of an alkaline soil [15]. Total dissolved solid (TDS) values are important parameter in determining the usage of water as groundwater with high TDS (>500mg/l) are not suitable for irrigation purposes. It is a measure of the combined content of all inorganic and organic substances present in water either in solution form or suspended form. The value of TDS ranged from 38.10 mg/l to 258.40 mg/l with a mean value of 67.85 mg/l (Table 1). This parameter is a proof of aesthetic characteristics of water. High TDS values indicate hard water and affect the taste and colour of water [16]. The pH value ranged from 6.48 to 7.25 with an average value of 6.87 (Table 1). The acceptable pH values ranged from 6.5 to 8.5 according to World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). The pH of water is an indicator of the water quality and extent of pollution. Water pH plays an important role in adsorption, absorption, sorption and cation exchange between soils as well as plants nutrient intake mechanism [15].

In terms of agricultural purposes, Sodium Adsorption Ratio (SAR) is an important parameter. It is a measure of the sodicity of the soil and provides vital information about the adsorption of sodium by soils. It is the proportion of sodium to calcium and magnesium which affect the availability of water to plants. High concentration of sodium in water or soil is detrimental to plants. The toxicity level in plants and trees are leaf burn and dead tissue along the edges of leaves. The adverse effect of sodium on the soil is a function of the ratio of sodium to the total cations in the irrigation water. The SAR was calculated using formula: $SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2}$. In the present study, the SAR values ranged from 0.0 meq/l to 2.19 meq/l with a mean value of 0.38 meq/l (Tables 1). According to [17], SAR values below 10.0 meq/l are good for irrigation. Based on the SAR values, with the exception of one sample in C3-S1 region, all the samples fall within the class of C1-S1 and C2-S1, signifying low sodium (alkali) hazard and excellent irrigation water (Fig. 2, Table 2). The salinity hazard diagram consists of four classes: C1/S1, C2/S2, C3/S3 and C4/S4, which signify low, medium, high and very high sodium (alkali) hazard. The dominance of the groundwater samples in C1-S1 and C2-S1 region is an indication that the groundwater in the study area is low sodium water and can be used for irrigation on virtually all kinds of soils and plants with no risk exchangeable sodium [18]. None of the samples fall within the unsuitable region (C4/S4). Sodium is introduced into the groundwater system through rainwater and dissolution of host rocks. High sodium content in soil results in stunted growth and yellowing of leaves in plants.

High SAR values (>10) could cause sodium to replace adsorbed calcium or magnesium, thereby damaging the soil structure. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing magnesium and calcium ions. The exchange process of sodium in water for magnesium and calcium in soil reduces permeability and eventually results in soil with poor drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry [19, 20]. The sodium or alkaline hazard in the use of water for irrigation is determined by absolute and relative concentrations of cations. If water used in irrigation is high in sodium and low in Calcium, the cation exchange complex may become saturated with Na. This can destroy the soil structure owing to dispersion of clay particles. The data show that the samples fall between S1, indicating low salinity and low sodium water for irrigation purposes for most soils and crops with no danger of development of exchange sodium and salinity, indicating good to excellent water.

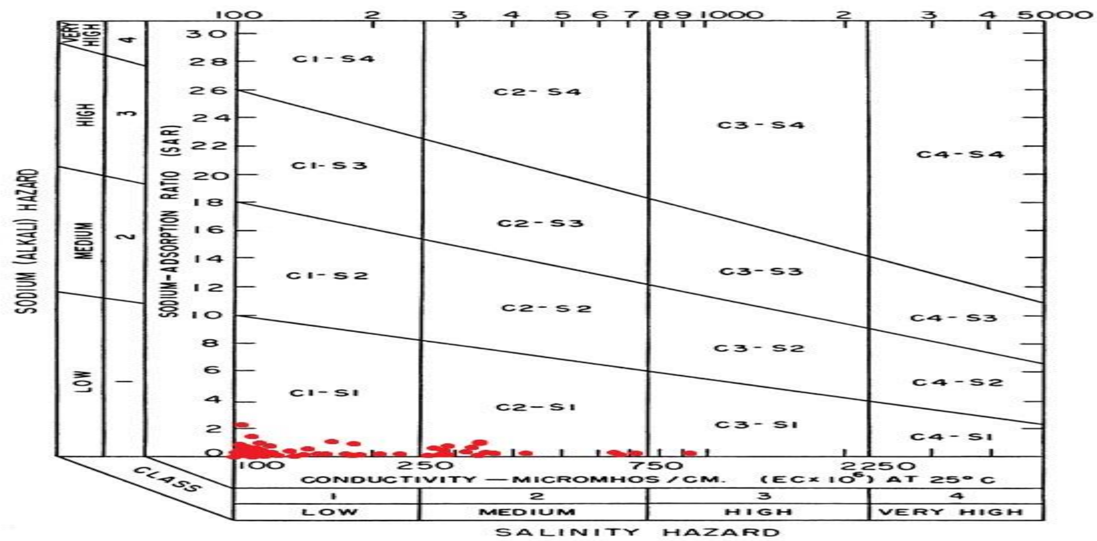

Fig. 2: U.S Salinity Diagram for the study area

Soluble Sodium Percentage (SSP)

Sodium percent is an important factor for studying sodium hazard. It is used also for adjudging the quality of water for irrigational purposes. High percentage sodium water for irrigation purpose may stunt the plant growth and reduces soil permeability [21, 22]. The SSP was calculated using the equation: SSP = $[(Na^+ + K^+) * 100] / [Ca^{2+} + Mg^{2+} + Na^+ + K^+]$. The SSP values ranged from 4.48 meq to l75.22 meq/l with a mean value of 40.46 meq/l (Table 1). The high deviation and variance as contained in Table 1, is an indication that the groundwater quality in the area is skewed by many factors. The TDS and EC display reasonable variation which suggests that the contaminants are from different sources. The SSP values were plotted against the EC values on the Wilcox diagram (Fig. 3) and are found to fall under the excellent to good categories. High sodium concentration in soil can affect internal drainage patterns in soil as release of calcium and magnesium ions are aided due to adsorption of sodium by soil particles especially clay [24]. Comparing the salinity hazard diagram (Fig. 2) and Wilcox diagram (Fig. 3), it can be deduced that one sample falls within the C3-S1 class and good to permissible portion respectively. This represent 2% of the total sample analyzed, which suggest that the groundwater from the study area can be excellently used for irrigation purposes without any side effect (Fig. 3, Table 2).

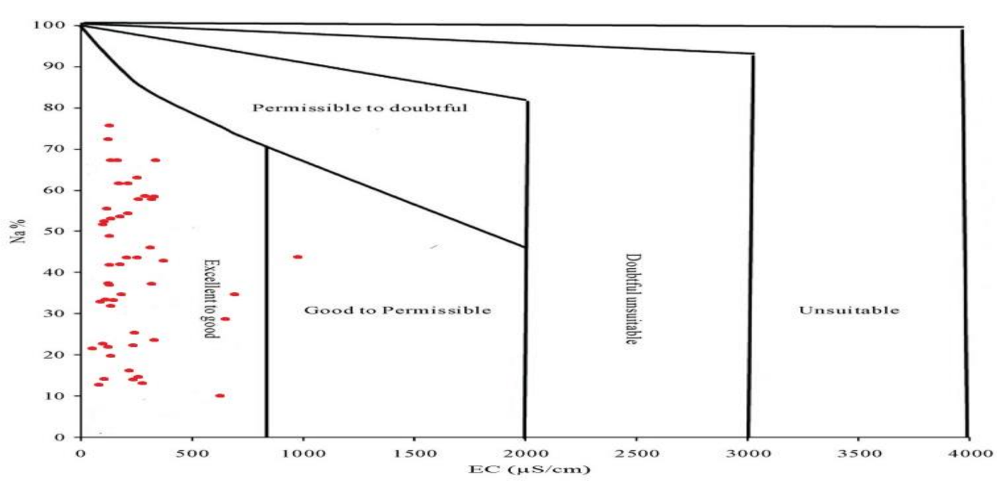

Fig. 3: **W**ilcox diagram for the Study Area

Permeability Index

The permeability of the soil is affected by the long term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate ratio, and soil type. According to [25], Permeability index is a criterion based on the solubility of salt and the reaction occurring in the soil solution from cation exchange for estimating the quality of irrigational waters. The permeability index is given by the formula: $PI = Na^+ + [\{HCO_3^-)^{1/2} / (Ca^{2+} + Mg^{2+} + Na^+)\} * 100]$. The value of the permeability Index ranged from 35.61 meq/l to 388.86 meq/l with an average value of 108.19 meq/l (Table 1). Permeability Index is classified under the following: class I (>75% permeability), class II (25-75% permeability) and class III (<25% permeability) orders (Fig. 4). The samples fall under class II and Class III waters categorized as moderate and poor respectively. The class III has about 25% of maximum permeability, which implies 75% of the irrigation water is non-permeable. The water in the soil is rarely available for plant use due to the fact that the soil is made up of tiny pore spaces which inhibit leachate/infiltration thereby reducing plants interaction with soil-water [26]. A good percentage of arable land within the study area falls within the Fadama soils, which is silty-clay/clayey soil that is characterized by high porosity and low permeability. The hydraulic properties of the soil can be improved upon by the introduction of loamy soil, organic manure as well as soil tillage will enhance the soil permeability in the area.

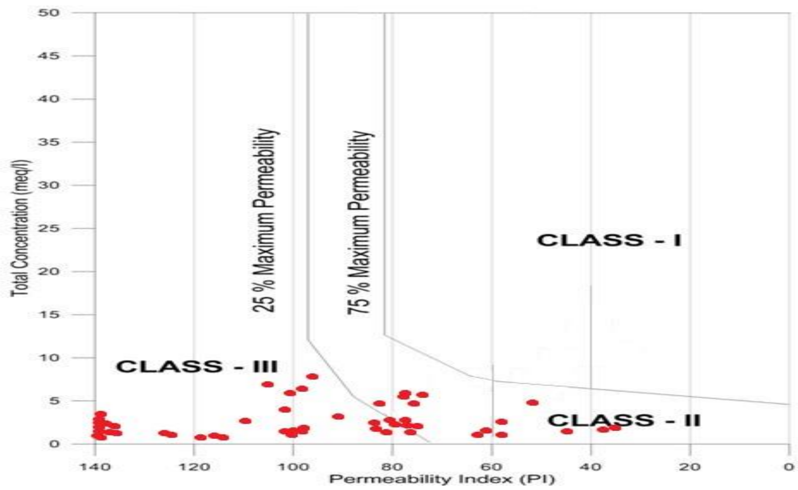

Fig. 4: Doneen's Chart for Permeability Index values

Residual Sodium Bicarbonate (RSBC)

The residual sodium carbonate index of water/soil signifies high pH, and by implication farm lands irrigated with such water are unproductive due to the deposition of sodium carbonate. The concentration of bicarbonate and carbonate influences the suitability of water for irrigation purposes. The RSBC is expressed by the equation: $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$. In the present study, the RSBC values ranged from -0.97 meq/l to 2.55 meq/l with an average value of 0.25 meq/l (Table 1). Residual sodium carbonate values should preferably be less than 1.25 to be considered suitable for irrigational purposes (Table 2). From the mean value as well as the low deviation and variance, majority of the samples fall below 1.0 meq/l which suggest good water for irrigation purposes. The outliers as observed from salinity hazard diagram (Fig. 2) and Wilcox diagram (Fig. 3) is about 2% and can be therefore considered insignificant.

Magnesium Adsorption Ratio (MAR)

Magnesium content of water is considered as one of the most useful factor to consider when evaluating the quality of water for irrigation. In many waters, calcium and magnesium maintain almost a state of equilibrium through natural process of rock-water interaction. However, when the concentration of magnesium far exceeds calcium, such water adversely affect crop yields as the soil become more saline and is no longer useful to plants [27]. The MAR is calculated using the formula: MAR = (Mg^{2+} * 100) / (Ca^{2+} + Mg^{2+}). The MAR values ranged from 12.10 meq/l to74.29 meq/l with a mean value of 32.05 meq/l (Table 1). The MAR classifies irrigation water into two broad classes: water having MAR <50 are considered suitable for irrigation whereas water with MAR > 50 is considered unsuitable (Table 3). Based on the available statistics, 95 % of the water samples has their MAR value less than 50% and naturally fall within the suitable category (Table 3).

Kelly's Ratio (KR)

Kelly's Ratio was devised by [28], and it is a measure of sodium ion concentration against calcium and magnesium ion concentrations. The Kelly's Ratio is given by the formula: KR = Na^{+} / (Ca^{2+} + Mg^{2+}). In the present study, Kelly's Ratio ranged from 0.0 meq/l to 2.45 meq/l with a mean value of 0.34 meq/l. Water with a KR value <1 are considered suitable for irrigation, while those with values >1 are considered unsuitable (Table 3).

Table 1: Statistical Summary of Computed Water Quality Parameters for Irrigation

Parameters	Minimum	Maximum	Range	Mean	Standard Deviation	Variance
SAR	0.00	2.19	2.19	0.37	0.52	0.27
SSP (%)	4.48	75.22	70.74	40.46	18.96	359.47
PI (%)	35.61	388.86	353.25	108.19	58.58	3441.10
RSBC (meq/l)	-0.97	2.55	3.52	0.25	0.64	0.40
MAR (%)	12.21	74.29	62.08	32.05	13.93	194.06
KR (meq/l)	0.00	2.45	2.45	0.34	0.55	0.31
EC (µs/cm)	75.50	420.70	345.20	115.30	23.00	45.62
TDS (mg/l)	38.10	258.40	220.30	67.85	15.84	31.24
pH	6.48	7.25	0.77	6.85	0.86	0.52

Table 2: Limits of some parameter indices for rating Groundwater Quality and its Suitability for Irrigation [15, 18, 22]

Category	EC (µS/cm)	RSBC (meq/l)	SAR	SSP (%)	PI (%)	Suitability for Irrigation
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 3: Classification of Irrigation water based on TDS, MAR and KR [25, 28, 29]

Class	MAR (%)	KR (meq/l)	TDS (mg/l)	Suitability for Irrigation
i	<50.0	<1.0	<1000.0	Suitable
ii	>50.0	>1.0	>1000.0	Unsuitable

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

Conclusion

The suitability of groundwater within Minna was evaluated for irrigation purposes in the present study. The concentration of the physical parameters (pH, EC and TDS) was within the allowable limit of irrigation water postulated by the World Health Organization and Nigerian Standard for Drinking Water Quality. The computed values of SAR, MAR, RSBC, SSP, KR and PI when compared with other known standards were also found to within the zone of water suitable for irrigation. The study established that the groundwater resources from Minna area of Niger State can be efficiently and effectively used for irrigation purposes.

Reference

[1] A. N. Amadi, P. I. Olasehinde, N. O. Obaje, C. I. Unuevho, M. B. Yunusa, U. N. Keke and I. M. Ameh (2017), Investigating the Quality of Groundwater from Hand-dug Wells in Lapai, Niger State, North-central Nigeria using Physico-chemical and Bacteriological Parameters. *Minna Journal of Geoscience*, 1(1), 77 – 92.

[2]. M. O. Aremu, G. N. Ozonyia and P. P. Ikokoh, (2011). Physicochemical Properties of Well, Borehole and Stream Waters in Kubwa, Bwari Area Council, FCT, Nigeria *Electronic Journal of Environmental, Agricultural and Food Chemistry*,10(6)**,** 2296-2304.

[3]. M. A. Dan-Hassan, P. I. Olasehinde, A. N. Amadi, J. Yisa and J. O. Jacob, (2012). Spatial and Temporary Distribution of Nitrate Pollution in Groundwater of Abuja, Nigeria. *International Journal of chemistry*, 4(3), 104-112, doi:10.5539/ijc.v4n3p104. 1916-9698, 1916-9701.

[4]. A. E. Edet and C. S. Okereke, (1997). Assessment of Hydrogeological Conditions in Basement Aquifers of the Precambrian Oban Massif, Southeastern Nigeria. *Journal of Applied Geophysics*, 36, 95-204.

[5]. J. O. Etu–Efeotor, (1998). Preliminary Hydrogeochemical Investigation of Subsurface Waters in Parts of the Niger Delta. *Journal of Mining and Geology*, 18, 103–105.

[6]. J. M. Isiaku and H. I. Ezeigbo, (2010). Assessment of Groundwater Quality Index for Jimeta-Yola Area.*http://www.academicjournals.org/article/article/380016080.*

[7]. S. K. Nag and D. Shreya, (2014). Quality Assessment of Groundwater with special emphasis on Irrigation and Domestic Suitability in Suri I and II Blocks, Birbhum District, West Bengal, India. *American Journal of Water Resources*, 2(4), 81 – 98.

[8]. G. I. Obiefuna and D. M. Orazuruike, (2010). Assessment of the Groundwater Quality in Yola area for Irrigation Purposes. *Water Resources*, 20(1), 32 – 52.

[9]. Adeleye, D. R., (1976),. The Geology of The Middle Niger Basin: In The Geology Of Nigeria, Ed. C. A. Kogbe., Elizabeth Press, Lagos. 283-287.

[10]. S. S. Dada, (2008). Proterozoic Evolution of the Nigeria – Boborema province. *Geologic Society London Special Publications*, 294, 121-136.

[11]. N. E. Bassey, S. S. Dada and O. A. Omitigun, (2006). Preliminary structural study of satellite imagery over basement rocks of northeast Nigeria and northern Cameroon; *Journal of Mining and Geology*, 42(1), 73-77.

[12]. A. E. Annor, P. I. Olasehinde and P. C. Pal, (1990). Basement Fracture Patterns in the Control of Water Channels – An example from Central Nigeria. *Journal of Mining Geology* 26(1), 5 -11.

[13] AOAC, (1990). *Official Methods of Analysis of the Association of Analytical Chemists*. Edited by Kenneth Helrich.

[14] APHA, (2008). Standards Methods for the Examination of Water and Wastewater. 19th Edition. *American Water Works Association*, Washington DC.

[15]. A. N. Amadi, N. G. Obaje, N. G. Goki, K. U. Abubakar, I. Shaibu and C. N. Nwakife, (2016). Studies on Water Quality in Suleja, Niger State for Domestic and Irrigational Purposes. *Nasara Scientifique: Journal of Natural and Applied Sciences*, 5(1), 16 – 29.

[16]. M. Kumar, K. Kumari, A. L. Ramanathan, and R. Saxena, (2007). A Comparative Evaluation of Groundwater Suitability for Irrigation and Drinking purposes in two intensively cultivated Districts of Punjab, India. *Environmental Geology*, 53, 553 – 574.

[17]. K. G. Quddus and M. W. Zaman, (1996). Irrigation Water Quality in some selected villages of Meherpur in Bangladesh. *Journal of Agricultural Science*, 23(1), 51 – 57.

[18]. R. S. Ayers and D. W. Wescot, (1985). Water Quality for Agriculture. FAO Irrigation and Drain, Paper No 29(1), 1 – 109.

[19]. Amadi A.N., Tukur A., Okunlola I.A., Olasehinde, P.I. and Jimoh M.O. (2015). Lithologic Influence on the Hydrogeochemical Characteristics of Groundwater in Zango, North-west Nigeria. *Natural Resources and Conservation*, 3(1), 11–18. doi:10.13189/nrc.2015.030103.

[20]. NSDWQ, (2007). Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard, NIS:554, 1-14.

[21]. D. M. Joshi, A. Kumar and N. Agrawal, (2009). Assessment of the irrigation Water Quality of River Ganga in Haridwar District India. *Journal of Chemistry*, 2(2), 285 – 292.

[22]. A. M. Michael, (1978). *Irrigation Theory and Practice*. Vikas Publishing House LTD, New Delhi, 713p.

[23]. Offodile, M. E. (2002). Groundwater study and development in Nigeria. *Mecon Geology and Engineering Service Limited*, Jos, Nigeria, (2nd Ed.), 239-244.

[24]. I. D. Doneen, (1964). Notes on Water Quality in Agriculture. Department of Irrigation, University of California, Davies, 48p.

[25]. F. M. Easton, (1950). Significance of Carbonate in Irrigation Water. Soil Science, 67(3), 128 – 133.

[26]. M. S. U, Talukder, S. M. Shirazi and U. K. Paul, (1998). Suitability of Groundwater for Irrigation at Kirimganj Upazila Kishoreganj. *Progress Agriculture*, 9, 107 – 112.

[27]. I. A. Richards, (1954). Diagonesis and Improvement of Saline and Alkali Soils. Agricultural Handbook 60, USDA and IBH Publication Coy LTD, New Delhi, India, 99p.

[28]. W. P. Kelly, (1940). Permissible composition and concentration of irrigated waters. In: *Proceedings of the ASCF66*, 607p.