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Suitability assessment of groundwater resources for irrigation around Otte Village, Kwara State, Nigeria

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Abstract: The continuous decline in the quality of available surface water resources due to increasing global pollution threats, put pressure on the need for assessment of suitability of groundwater resources for irrigation purpose. This work assesses the physical and chemical characteristics of the local groundwater resources around the Otte Village, Nigeria, to determine its suitability for irrigation. The methods involve chemical analysis of the water samples obtained from 12 shallow hand-dug wells, and interpretation of the results based on acceptable guidelines. The results of the total dissolved solids (90 – 534 mgL^{-1}), Electrical Conductivity (222 – 544 µS/cm), Soluble Sodium Percentage (-1.70 – 150.05 %), Permeability Index (4.15% - 22.57 %), Residual Sodium Bicarbonate (-1.89 – 5.63 $meqL^{-1}$) and Sodium Adsorption Ratio (1.77 – 171.9) obtained for the water samples indicate that the geology appears to have greater influence on the chemical transformation of the groundwater resources, compares to any possible effects due to the anthropogenic activities. This work concludes that the water samples obtained from the areas underlain by the Migmatitic gneiss (W1 – W10) appear to be relatively suitable for irrigation compared with those underlain by the Granitic gneiss (W11 – W12). Further work is required to quantify the effects of the variability of the groundwater quality on the crop yield, as well as to assess any possible effects of the seasonal variations on the conclusions.

Key words: Irrigation, groundwater quality, suitability, anthropogenic, geology

1. Introduction

The global importance of groundwater as a major source of freshwater for agricultural and domestic uses cannot be over-emphasized. Approximately 97% of the earth's useable fresh water is stored as groundwater (Delleur, 1999). Also, groundwater constitutes an important component of the water cycle, and it is partly used to maintain soil moisture, stream flow and wetlands, as well as being the sources of drinking water, agricultural and industrial supplies in many parts of the world. Qiu (2010) estimated that groundwater respectively constitutes approximately 40 % and 70 % of the total global water resources being used for irrigation and domestic purposes. These proportions could potentially increase due to the continuous decline in the quantity and quality of available surface water resources, largely caused by the increasing global pollution threats from industrialization and urbanization, as well as the effects of the climate change. Therefore, the requirement for the assessment of suitability of groundwater resources for drinking and irrigation purposes is becoming increasingly important and this is demonstrated by the relatively large number of recent studies in this field (Peiyue *et al.* 2011; Tadesse *et al.* 2009). Generally, the suitability of groundwater for agriculture and domestic purposes largely depends on the site specific quality of the water, with possible temporal variations caused by climatic conditions, as well as the

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residence time of water within the aquifer materials and anthropogenic activities. Uncontrolled applications of fertilizers and manure, as well as indiscriminate disposal of domestic sewage could further contribute to degradation of groundwater quality, especially in the developing countries. In certain conditions, especially where there is accumulation of sodium ions in the soil structure due to extended use of certain irrigation water, could cause deterioration in the soil physical properties, and thereby results in the decrease of the crop yield. Hence, this work intends to assess the physical and chemical characteristics of the local groundwater resources around the Otte Village in order to determine its suitability for the purpose of irrigation.

2. Description of the study area

The area of study in situated around the Otte Village in Asa Local Government of Kwara State, Nigeria. It covers approximately 114 km^2, and bounded by longitudes 4^0 21′ and 4^{0}26′E and latitudes 8^0 15′ and 8^{0}20′ N (Figure 1).

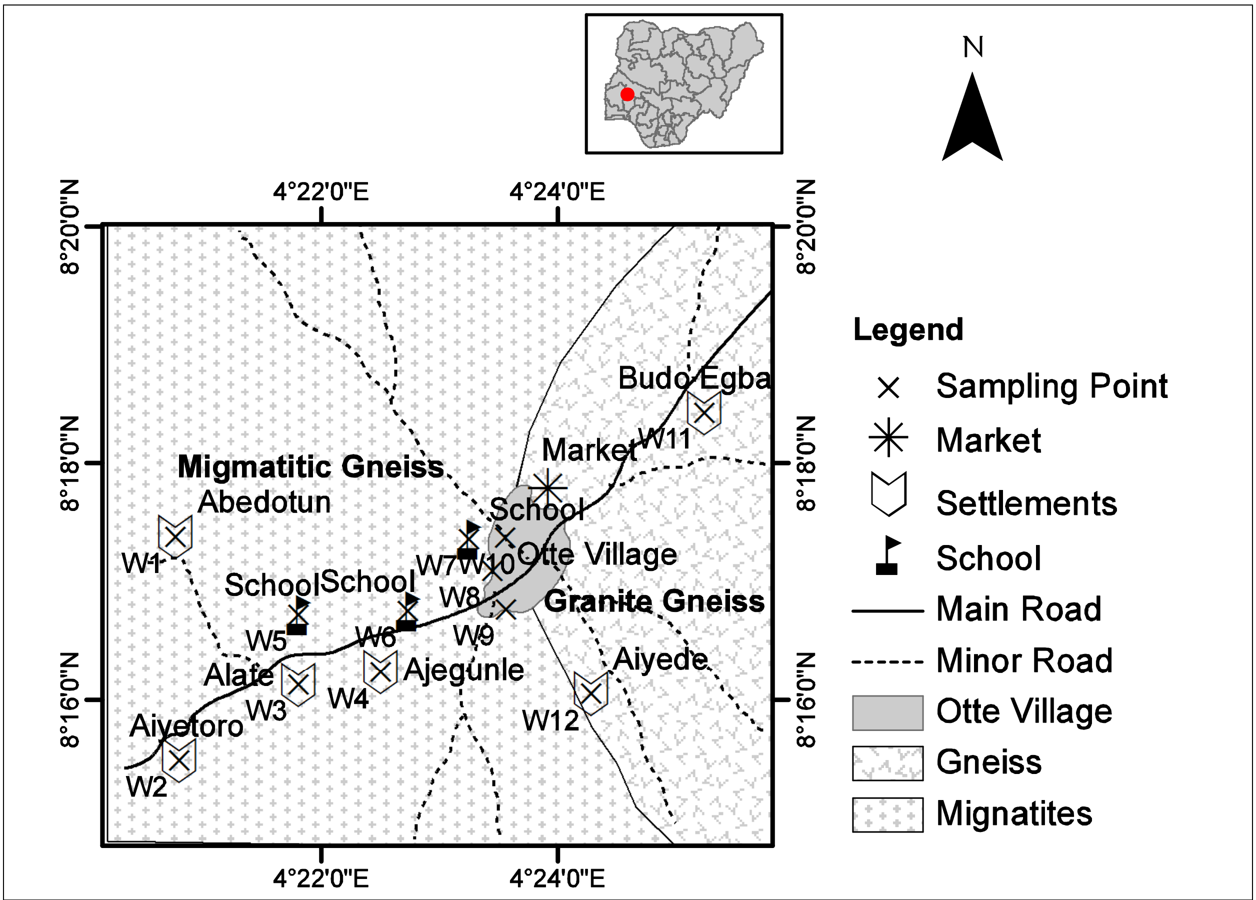

Figure 1: Description of the study area

There are too distinct seasons namely the rainy season (April – October) and the dry season (November – March) within the area. The rainy season is characterized by high rainfall with an average annual rainfall of 1237mm (Olayinka, *et al*., 2000), while the dry season is characterized by dry, dust-laden wind. The average temperature reaches a peak value of 28.8^{0}C in February and a minimum value of 24.5^{0}C in August. The vegetation in Otte village area is tropical rain forest and comprises shrub, light forest, savannah grassland and palms which is thickest near streams and rivers. The surface topography of the study area is described as undulating, with elevation ranging between 290m and 373m above the mean sea level. The topography is dominated by three major landform units namely hills, plains and river valleys. The hills are the most striking features, although constituting less than 20 % of the total surface. The plains are relatively more extensive, with the elevation ranging between 180 m and 210 m above the mean sea level, while the river valleys are the narrowest, and characterized by the rivers cutting into the flood plain.

Geologically, the study area is underlain by the basement complex rocks, essentially consisting migmatitic gneiss and granitic gneiss, and partially overlain by weathered outcrops and sediments. There are potholes on the outcrops as well as pegmatitic veins, which are laterally displaced by faults and joints. The igneous and metamorphic rocks of the basement complex are crystalline in nature and therefore have low primary porosity, and lack the hydraulic conductivity required for the groundwater flow. Hence, the overlying weathered rocks and sediments constitute the aquifer units in the area, and are probably enhanced by the presence of the observed structural features. The major source of water supply within the area is through the shallow hand-dug wells, and complimented by surface water. The hand-dug wells and surface water sources are particularly susceptible to anthropogenic activities, including the use of pit latrines by the local residents and indiscriminate dumping of house hold solid waste. These in turn contributes to the occurrence of extensive pollution in the study area, especially during heavy rainstorms.

3. Methodology

The methods involve collecting water samples from 12 shallow hand-dug wells, and subsequently carrying out of chemical analysis of the major parameters. The relatively simplistic lithological distribution coupled with the rural development of the study area justifies the relatively few sampling locations used in the study. The 12 wells were randomly selected from the list of initial inventory of the hand-dug wells carried out, though the selection process was intuitively guided by the need for spatial representation, accessibility to the sampling points and the geology. All the water samples were collected in the month of December during the dry season, and were analyzed for the following parameters: pH, Electrical Conductivity (EC), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Bicarbonate (HCO_3^{-}), Chloride (Cl^{-}), Sulphate (SO_4^{2-}) and Nitrate (NO_3^{-}). Others include Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC), Electrical Conductivity (EC), Magnesium Adsorption Ratio (MAR), Kellys Ratio (KR), Total Dissolved Solids (TDS) and Permeability Index (PI). The locations of the 12 wells (W1 – W12) where water samples were taken for the analysis are presented in Figure 1. The water samples were bailed from below the static water levels of the shallow wells, using a stainless steel bailer, and then filtered for storage into a thoroughly washed, 1 litre plastic bottle, and carefully sealed and labeled for the analyses.

The chemical analyses were performed in the Kappa laboratory located in Ibadan, Nigeria, employing standard methods of Atomic Absorption Spectrophotometry for cations and convectional titration for anions. The Sodium Absorption Ratio (SAR) was calculated based on the Richards (1954), and presented in Equation 1. Also, the Soluble Sodium Percentage (SSP) and the Residual Sodium Bicarbonate (RSBC) were calculated according to the relationships presented by Todd (1980) and Gupta (1987), and presented in Equations 2 and 3, respectively.

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

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

$$RSBC = HCO_3^- - Ca^{2+} \quad (3)$$

The permeability Index (PI) was calculated according to Doneen (1964) using Equation 4, while the Magnesium Adsorption Ratio (MAR) was calculated based on Raghunath (1987), as presented in Equation 5. The Kellys Ratio (KR) (Kelly 1963) as well as the Total Dissolved Solids (TDS) (Richards 1954) were calculated using Equations 6 and 7, respectively.

$$PI = \frac{Na^+ + \sqrt{HCO_3^-} \times 100}{Ca^{2+} + Mg^{2+} + Na^+} \quad (4)$$

$$MAR = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (5)$$

$$KR = \frac{Na^+}{Ca^{2+} Mg^{2+}} \quad (6)$$

$$TDS = 0.64 \times EC \times 106 \quad (7)$$

where EC is the Electrical Conductivity (μS/cm), and the TDS is expressed as mgL^{-1}.

Also, the ions contained in Equations 1 – 6 are expressed in $meqL^{-1}$. The interpretation of the results of the analysis were based on the guidelines and the standards specifications presented by WHO (2006) for irrigation water quality.

4. Results and discussions

The statistical summary of the results of the analyses as well as the regulatory requirements are presented in Table 1, which also underpins the basis for the determination of the suitability of the groundwater for the irrigation purpose. The electrical conductivity (EC) provides indication for a potential salinity hazard of the water, and possible consequences for the productivity of the crop. Generally, high EC values can potentially inhibits plants to compete with ions in the soil solution. That is, the higher the value of the EC, the less the amount of water that is available to plants. Joshi *et. al*, (2009) concludes that the water available for plants in the soil solution decreases proportionately as the EC increases. Richard (1954) provided an interpretative relationship between the values of the EC and the degree of suitability of certain quality of irrigation water, and this is presented in Table 2. Also, some parameter indices for the rating of the suitability of groundwater for irrigation are presented in Table 3. The values obtained for EC in this work ranges between of 222.0 – 544.0 μS/cm, and these values are less than the permissible limits of 1000 μS/cm (WHO, 2006). According to Richard (1954), all the water samples have low to moderate saline water (see Table 2), and therefore described as safe for irrigation purpose.

Also, the range of values obtained for the Total Dissolved Solids (TDS) is between 90 mgL^{-1} to 534 mgL^{-1} (see Table 1), with a mean value of 370.8 mgL^{-1}. These values are less than the permissible limits of 1000 mgL^{-1}, recommended by both WHO (2006) and Robinove *et. al* (1958). According to the latter authors, these water samples are classified as Non Saline, and therefore excellent for irrigation purpose. Generally, when the salts of calcium, magnesium, sodium, potassium are present in excessive quantities, they may prove to be injurious to plants by reducing the osmotic activities of the plants and therefore preventing adequate aeration. Further to this, approximately 85% of the values obtained for the Sodium Adsorption Ratio (SAR) during the present study are generally less than 3, with the exception of two locations (W11 and W12), where the values are significantly higher than 3. According to the rating indices presented in Table 3, these water samples (i.e. W1 – W10) are described as 'Excellent' for irrigation purpose. The SAR values obtained for W11 and W12 are 171.92 and 125.84, respectively, and these are significantly higher than the recommended maximum permissible limit of 26 (see Table 3). Therefore, the water samples obtained from W11 and W12 are rated as 'Poor' for the purpose of irrigation.

The range of values obtained for the Magnesium Adsorption Ratio (MAR) within the study area vary between 1.33 and 30.63 %. Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters, but increasing amount of magnesium in water will increase the salinity of the water and therefore decline the crop yield (Joshi *et. al,* 2009). The values obtained in this work are less than 50% and therefore, according to Ayers and Westcot (1985), indicates that, based on the MAR values, all the waters are considered suitable with no hazardous effects to the soil. The values of the Permeability Index obtained in this work ranges between 4.15% - 22.57 %. Generally, the soil permeability is affected by the long term use of irrigated water with high values of total dissolved solids and sodium bicarbonate. However, based on the classification presented by Doneen (1964), the results obtained in this work falls within the Class I category, which are described as excellent irrigation water.

Conversely, the Soluble Sodium Percentage (SSP) parameter provides an estimate of the percentage of sodium ions present in the water sample, which further provides an indication of the probable hazard that could be resulted from accumulation of sodium ions. Therefore, SSP is frequently used in the determination of the suitability of water for irrigation purpose. According to Joshi *et. al* (2009), a high percentage of sodium in the water for irrigation purpose can potentially stunt the plant growth and reduces soil permeability. In this work, the values obtained for the SSP parameter (See Table 4) range between -1.64% and 150.05 %. According to Wilcox (1948) (Table 3), 85% of the SSP values obtained in the present work are higher than the recommended permissible limit of 80%, and therefore these water samples (W1 – W10) are classified as 'Poor' for the purpose of irrigation. Water samples obtained from W11 and W12 have significantly low values of less than 1.0, and therefore are classified as 'Excellent' for irrigation.

Furthermore, the Residual Sodium Bicarbonate (RSBC) values obtained for the water samples vary between -2.49 and 5.62 meqL^{-1}. Generally, the concentration of bicarbonate and carbonate within the soil influences the suitability of water for irrigation purpose, because water samples with high RSBC value tend to have relatively high pH values. Therefore land irrigated with such water becomes infertile owing to deposition of sodium carbonate (Eaton, 1950). In this work, the maximum value obtained for the RSBC for the water samples obtained from W1 – W10 is -1.89 meqL^{-1}. Based on the rating indices presented in Table 3, these water samples are described as 'Good' for irrigation. However, the RSBC values obtained from the water samples W11 and W12 are 5.62 and 3.89 meqL^{-1}, respectively. These values are greater than the recommended value of 2.5 meqL^{-1} and therefore are described as 'Poor' for irrigation purposes. Also, the ranges of values for the kellys Ratio (KR) obtained for the W1 – W10 and W11 – W12 water samples are 1.33 – 1.67%, and 4.85 – 5.92%, respectively. The KR values obtained in W1 – W10 water samples are generally lower than that obtained from the W11 and W12 water samples, but the KR values obtained are higher than the permissible limit of 1.0 recommended by Ayers and Westcot, (1985) in all the samples. The results obtained for the EC, TDS, MAR and PI show that the values obtained for all the water samples are within the acceptable limits of the regulatory standards for the purpose of irrigation. However, the results obtained for the SAR and RSBC suggests that only the values obtained for the group of water samples W1 – W10 are within the recommended limits and therefore suitable for irrigation purpose. The W11 – W12 samples have values that are significantly higher that the recommended values. The pattern of the results of the chemical analysis appears to be delineated along two groups, namely W1 – W10 and W11 – W12. Geologically, all the water samples W1 – W10 are located within the area delineated as underlain by the Migmatitic gneiss, while the W11 – W12 water samples are located within the area underlain by Granitic gneiss. This suggests that the geology played a major role in the transformation of the chemical constituents of the water samples. It is expected that the anthropogenic activities will also have some degree of influence in the chemical transformation of the local groundwater resources; however these effects are not apparent in the results of the analysis.

Table 1: Results of the physical and chemical analysis

PARAMETERS	Minimum	Maximum	Mean	Standard Deviation	WHO (2006)
Colour (Hazen unit)	0.0	2.0	0.9	0.7	15.0
Turbidity (FTU)	0.0	3.0	1.5	0.9	5.0
pH	6.5	7.2	6.7	0.2	6.5 -8.5
Electrical Conductivity (µS/cm)	222.0	544.0	370.8	91.1	1000.0
Total Dissolved solid (mgL^{-1})	90.0	534.0	360.6	164.1	1000.0
Alkalinity as $CaCO_3$ (mgL^{-1})	0.5	2.2	1.4	0.5	50.0
Total Hardness (mgL^{-1})	36.0	55.7	45.8	6.0	500.0
SO_4^{--} (mgL^{-1})	0.0	0.2	0.1	0.1	250.0
Cl^- (mgL^{-1}	2.6	8.2	5.4	1.5	500.0
NO_3^- (mgL^{-1})	0.0	0.2	0.1	0.1	45.0
HCO_3^- (mgL^{-1})	0.0	0.1	0.0	0.0	94.6
PO_4^{---} (mgL^{-1})	0.0	1.2	0.4	0.4	0.1
Fe^{++} (mgL^{-1})	0.1	0.2	0.1	0.1	-
Na^+ (mgL^{-1})	39.3	59.3	50.3	6.4	200.0
K^+ (mgL^{-1})	10.3	16.7	13.3	1.8	55.0
Ca^{++} (mgL^{-1})	32.9	49.9	40.7	5.0	75.0
Mg^{++} (mgL^{-1})	3.5	8.3	5.3	1.3	20.0

Table 2: Suitability of irrigation water based on the EC values (Richard, 1954)

S/N	Electrical Conductivity (μS)	Water Type	Suitability for irrigation
1	< 250	Low saline water	Entirely safe
2	250 - 750	Moderately saline	Safe under most conditions
3	750 - 2250	Medium to High saline	Safe only with permeable soil and moderate leaching
4	2250 - 4000	High salinity	Unfair for irrigation
5	4000 - 6000	Very high salinity	
6	> 6000	Excessive salinity	

Table 3: Some parameter indices for rating the sustainability of groundwater quality for irrigation (Ayers and Westcot, 1985, Eaton, 1950 and Wilcox, 1948).

Class	EC (μS/cm)	RSC (mgL^{-1})	SAR	SSP (%)	Sustainability for Irrigation
I	< 117.51	< 1.25	< 10	< 20	Excellent
II	117.51 - 508.61	1.25 – 2.5	10 – 18	20 – 40	Good
III	> 503.61	> 2.5	18 – 26	40 – 80	Fair
IV	-	-	> 26	> 80	Poor

Table 4: Values for the parameter indices

Well Number	SAR	SSP (%)	MAR (%)	KR $meqL^{-1}$	PI %	TDS mgL^{-1}	RSBC $meqL^{-1}$	EC (μS/cm)
W1	1.77	121.55	18.51	1.33	4.15	513.00	-1.89	373
W2	2.22	138.91	19.82	1.61	5.23	505.00	-1.99	445
W3	2.33	150.05	19.37	1.65	5.55	534.00	-2.05	325
W4	1.85	119.51	18.96	1.38	4.46	385.00	-2.00	383
W5	1.67	102.89	30.63	1.58	4.86	376.70	-2.31	444
W6	1.89	110.89	22.46	1.48	5.29	250.00	-2.49	376
W7	1.85	114.67	23.18	1.48	4.96	126.70	-2.34	358
W8	1.83	116.37	23.41	1.47	4.78	158.30	-2.14	423
W9	2.23	143.15	22.45	1.67	5.48	521.70	-1.98	224
W10	1.83	124.26	21.7	1.44	4.41	475.00	-1.89	332
W11	171.92	-1.70	1.87	4.85	22.57	391.70	5.62	544
W12	125.84	-1.64	1.33	5.92	18.18	90.00	3.89	222

Table 5: TDS values for irrigation use (Robinove *et. al.*, 1958)

Classification	Total Dissolved Solids (mgL^{-1})
Non saline	< 1000
Slightly saline	1000 - 3000
Moderately saline	3000 – 10,000
Very saline	> 10,000

5. Conclusions

The groundwater quality of Otte Area of Kwara State, Nigeria was assessed for its irrigational suitability. The values of Total Dissolved Solids (90 – 534 mgL^{-1}), Electrical Conductivity (222 – 544 μS/cm), Soluble Sodium Percentage (-1.70 – 150.05 %), Permeability Index (4.15 - 22.57 %), Residual Sodium Bicarbonate (-1.89 – 5.63 $meqL^{-1}$) and Sodium Adsorption Ratio (1.77 – 171.9) obtainable for the water samples indicate that the water quality was partitioned along the geological boundary. The geology appears to have greater influence on the chemical transformation of the groundwater resources, compared to any possible effects due to the anthropogenic activities within the study area. Therefore, this work concludes that the water samples obtained from the areas underlain by the migmatitic gneiss (W1 – W10) appear to be relatively suitable for irrigation purpose compared to those underlain by the granitic gneiss (W11 – W12). Further work is required to quantify the effects of the variability of the groundwater quality on the crop yield, as well as to assess the any possible effects of the seasonal variations on the conclusions.

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