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Quality Assessment of Groundwater in Abuja, Nigeria for Domestic and Irrigation Purposes

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Abstract

Evaluation of the groundwater characteristics in Abuja for household and irrigation purposes was carried out in this study for both rainy and dry seasons for three consecutive years. The groundwater in the region is alkaline with bicarbonate dominating the major ions. The values of electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH) were higher in wet season than dry season and it can be attributed to rock-water interaction, dilution, dissolution and chemical weathering. The value of SAR ranged between 0.05 to 0.44 with a mean value of 0.22 for the rainy season and 0.07 to 4.20 with an average value of 1.24 for the rainy season. The mean value of SSP, MAR, RSBC, PI and KR are 37. 95%, 32.21%, 0.31meq/l, 119.31% and 1.11 meg/l, respectively for the dry season and 39.49%, 33.46%, 0.06meq/l, 72.67% and 0.62meq/l, respectively for the rainy season. The average concentration of TDS, EC and TH in the dry season are 123.50mg/l, 191.28µs/cm and 62.57mg/l while their corresponding values in the rainy season are 224.33mg/l, 300.50µs/cm and 82.32mg/l. Considering on the outcome of the analyses and interpretation of water quality parameters (WQI, SAR, SSP, MAR, RSBC, PI, KR, TH, TDS and EC), the appropriateness of groundwater in Abuja for irrigation purposes is in the order of good to excellent and poor for domestic use due to high nitrate content, which is due to urban pollution. The plotting of the salinity diagram falls within the low salinity zone, which is an indication of low sodic water and further confirms the appropriateness of the groundwater system for irrigation purposes. The variation in the yearly results obtained during the three consecutive years of this study was insignificant which implies that the groundwater chemistry in the locale is fairly constant, characteristic of slightly contaminated groundwater system. Based on the findings, the groundwater in Abuja is suitable for irrigation purposes and poor for domestic purposes.

Keywords: Quality Assessment, Groundwater, Irrigation Purposes, Domestic Use, Abuja

Introduction

The availability of clean fresh water is one of the greatest challenges facing mankind today as millions of people especially in rural areas still lack access to potable water (Amadi *et al.*, 2015). The developmental programmes since the oil boom era in Nigeria and the steadily growing population in the last four decades have put tremendous pressure on the nation's available resources (Adelana and Olasehinde, 2003). In the same vein, the projected water supply to the Federal Capital Territory, Abuja, Nigeria, has become grossly inadequate. Public water supply from Lower Usuma Dam Water Works, with a production capacity of 8000 m^3/hour of treated water and designed to serve a population of 500,000 people about 25 years ago has failed to meet the growing demand for water as a consequence of population increase and urbanization (DanHassan *et al.*, 2012; Okunlola *et al.*, 2015).

Within the last decade, therefore, there is erstwhile significant rise in groundwater demand and utilization in the Federal Capital Territory, Abuja, Nigeria, especially for institutional, domestic and irrigational purposes. This is further manifest in the peripheral communities where greater part of the population live (Olasehinde and Adelana, 2004). Over the years, there has been an unprecedented influx of people to the Federal Capital Territory for economic reasons and for seeking safe havens, away from the crisis-ridden towns in the neighbouring states. With an unprecedented growth rate of 13% and a population of over 6.7million people living on a territory of about 8,000 square kilometers, Abuja is the fastest growing city in Africa ((Adelana *et al.*, 2001; Olasehinde *et al.*, 2001).

It is therefore important to explore for groundwater sources to supplement the limited surface water sources to meet the irrigation needs of the populace. Both the quantity and quality aspects are essential for resource evaluation. Consequently to meet the increasing demand for water for irrigational, domestic and industrial purposes, there has been heavy dependence on groundwater especially in the rural communities where groundwater seems to be the only option for the provision of potable water. The weathered/fractured basement and sandstone formation in the study area form significant aquifer systems supporting the provision of drinking water to the populace and small-scale industries.

Natural water either surface or ground sources, contains dissolved solids and gases as well as suspended matter. The quantity and quality of these constituents depend on geologic and ecological factors, and they are endlessly varying as a consequence of the action of water with the contact media and activities of man (Amadi *et al.*, 2014). The present study aims at looking into the synergy between quality and quantity of available groundwater in the study area for irrigation purposes in order to meet their food demand. The protracted utilization of certain water for irrigation purposes accounted for the reduced harvests resulting from the worsening in the soil physical properties. The unfavorable effects of irrigation water quality on soil physical properties is related to the buildup of sodium ion on the soil exchange complex, which imparts unsteadiness to the soil aggregates and whose interruption followed by spreading of clay particles results in blockage of soil pores. The water quality utilized for irrigation is consequently indispensable for the yield and quantity of crops, preservation of soil productivity and protection of the environment. Simultaneously, the quality of irrigation water is vastly influenced by the land constituents of the water source.

According to Nag and Shreya (2014), several chemical constituents influence the appropriateness of water for irrigation and the factors include:

1. The total concentration of soluble salts (which is largely interrelated to the definite conductance of water)
2. The relative quantity of sodium to calcium and magnesium
3. The concentration of boron
4. The virtual amount of bicarbonate to calcium and magnesium

The study, therefore, evaluates the suitability of groundwater from shallow aquifers in Abuja for domestic and irrigation purposes. It is believed that the baseline information provided in the study will help in solving the problem of acute food and water shortage in the Federal Capital Territory, Abuja.

Materials and Methods

Description of the study area

In 1978, Abuja, the Nigerian Federal Capital Territory was created, following the resolution to move the nation's capital away from Lagos in the southern coastal area to a more central place inside Nigeria, devoid of domination by any of the major ethnic groups. The factors considered for the location of the "new" capital were justified by the Federal Government in Decree No. 6 of 1976. It lies approximately between longitudes $6^0 46'$ and $7^0 37'$E and latitudes $8^0 21'$ and $9^0 18'$N (Figure 1). The study area covers an area of about 5,000 km^2 of the 8000 km^2 of the territory. The Federal Capital Territory is bordered by Kaduna State to the north, Kogi State to the south, Niger State to the west and Nasarawa State to the east.

Relief and Drainage

The topography of the FCT is diverse with the lowest elevations in the Territory within the farthest south-west at the floodplains of the River Gurara (76 m above sea level). From here, the land rises unevenly northwards, eastwards and northwestwards. The peak part of the territory is found in the northeast where there are many peaks above 760 metres beyond sea level. Hills crop up as clusters and long ranges all over the Territory.

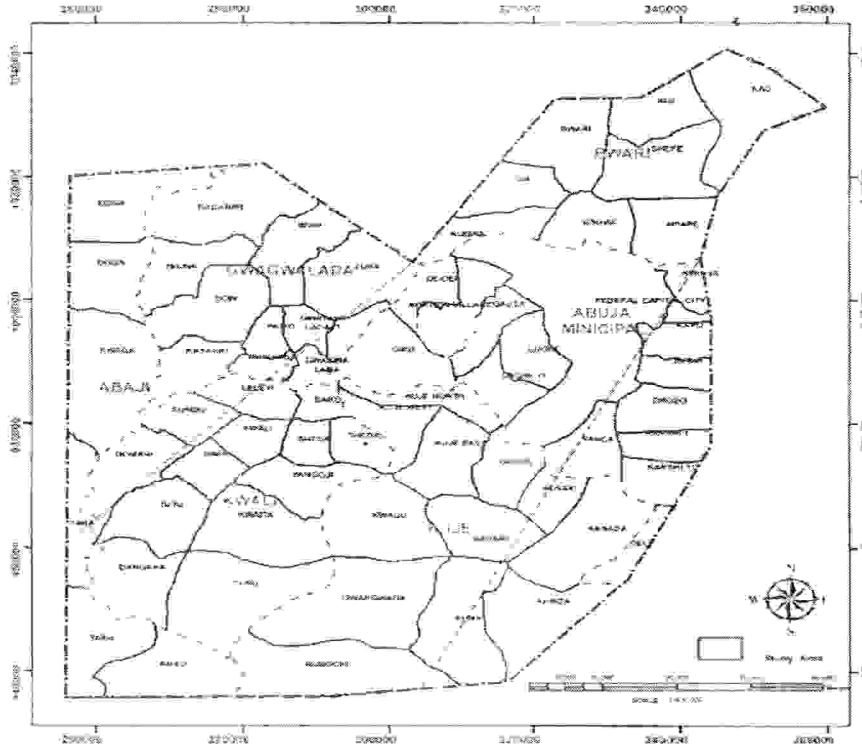

Fig. 1: Map of Abuja, Nigerian's Federal Capital

The most well-known of these comprise the Gawu range in the northwest, the Bwari-Aso range in the northeast, Idon Kasa to the northwest of Kuje, Wuna range in the north of Gwagwalada and the Wasa-Sukuku range running across the centre of the Territory from Wasa in the east to Kwali in the west. The topography of Abuja is diverse with the lowest elevations in the farthest southwest with numerous hills occurring in the northeastern portion. The rivers take their cause from the hills in the northeast and flows to the southwestern. The two main rivers are the River Gurara and River Usman, which come together at Nyimbo village to form an offshoot of

River Niger in the south.

Geology of the Study Area

Abuja is underlain by Precambrian rocks belonging to the Nigerian Basement Complex, which envelop about 85% of the surface of the land while the remaining 15% are covered by Cretaceous rocks of sedimentary origin from the Bida Basin (Figure 2).

The main lithologic units associated are:

(a) The Older granites
(b) The Metasediments (schist, phyllite and quartzite)
(c) The Migmatite-Gneiss Complex
(d) The Nupe Sandstones of the Bida Basin

The Older Granites are understood to be pre-, syn- and post tectonic rocks, which intrude and intersect equally the migmatite-gneiss-quartzite complex and the schist belts (Rahaman, 1988; Obaje, 2009). They have a broad variety in both age (750 – 450 Ma) and composition and exhibit diverse and longer magmatic cycles related to the Pan African orogeny (Mc Donald, 2008). The Older granites consist of Biotite Granite (coarse porphyritic), large intrusive masses generally oblique in nature forming dissected zones of the Zuma/Bwari – Aso hills and outcrops of the Gwagwa Plains, Biotite Granite (fine to medium grained) forms ridge row trending northeast – southwaest throughout the territory; Ryolite, forming small round intrusives bounded by porphyritic gneiss in the Usuma Valley in the northeastern part of the study area.

Sampling

A total of 65 groundwater samples were collected from boreholes and hand-dug wells yearly, covering two seasons: dry and rainy seasons, for three consecutive years, from October, 2011 to September, 2014. The sampling was carried out for the same site. The container was entirely filled with water taking care that no air bubble was trapped inside the water sample. The bottles were sealed with double plastic caps in order to prevent evaporation and instantly conveyed to the laboratory for the relevant physico-chemical analyses.

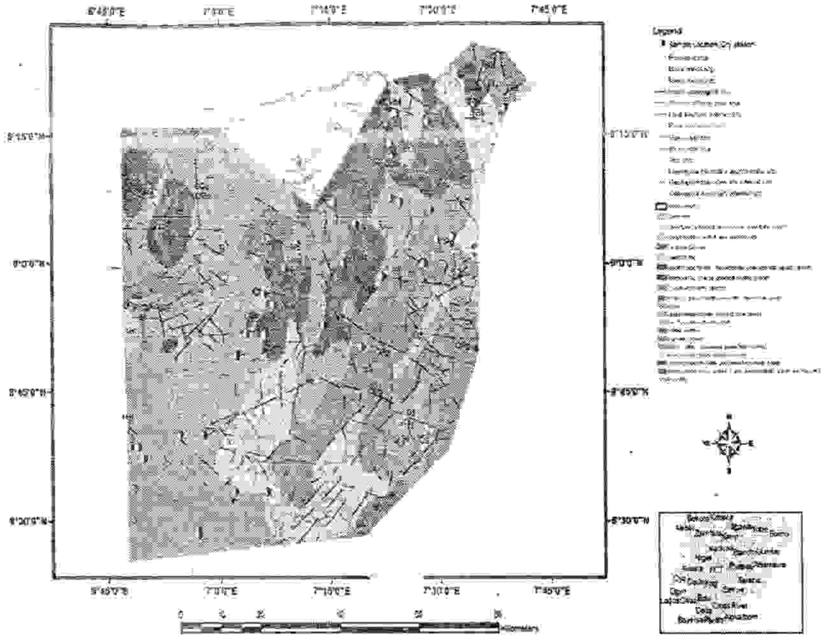

Fig. 2: Geological map of Abuja showing sample locations

Laboratory Analysis

The groundwater samples were analyzed in the laboratory for major ionic concentrations using standard methods (APHA, 2008). Calcium and magnesium were determined titrimetrically using standard EDTA, chloride by normal $AgNO_3$ titration, bicarbonate by titration with HCl, sodium and potassium by flame photometry. The pH, total dissolved solids and electrical conductivity were determined in the field using pHTestr 2, ECTestr+ by Eutech Instruments and DIST 3 by Hanna Instruments respectively. The sulphate and phosphate were determined by Spectrophotometer CL 22D.

Data Treatment and Classification Model

The essential parameters affecting the aptness of water for irrigation purposes are as follows: electrical conductivity (EC), soluble sodium percentage (SSP), total dissolved solids (TDS), magnesium adsorption ratio (MAR), sodium adsorption ratio (SAR), permeability index (PI), residual sodium bicarbonate (RSBC) and Kelly's ratio (KR). The results of the analyses were further explained using graphical representations like United States Salinity Hazard Chart and the Doneen plots.

Results and Discussion

Electrical Conductivity (EC)

The mainly significant water quality guideline on crop yield is the water salinity vulnerability as determined by electrical conductivity (EC). The principal outcome of water with high EC on crop productivity is the failure of the plant to vie with ions in the soil solution for water (physiological drought). The higher the EC, the less water is obtainable to plants nonetheless the soil may look as if wet. In view of the fact that plants can merely transpire water (pure water), utilizable plant water in the soil solution reduces dramatically as EC increases (Amadi *et al.*, 2013).

On the basis of electrical conductivity, irrigation indices categorization is given in Table 3. For the water samples taken in the dry and rainy seasons, the electrical conductivity values vary from 10 µs/cm – 800 µs/cm and 10 µs/cm – 1420 µs/cm respectively (Tables 1 and 2). They fall within the irrigation water categories as excellent category (47.5%), good category (50%) and fair category (2.5%) for dry season samples while rainy season samples are classified as excellent category (35%), good category (40%) and fair category (25%) as shown Table 3; Figures 3, 4, 5 and 6.

Soluble Sodium Percentage (SSP)

Sodium percent is an essential aspect for investigating sodium hazard. It is as well used for adjudging the quality of water for agricultural objectives. High percent sodium water for irrigation purposes may stunt plant growth and reduces soil permeability (Joshi *et al*, 2009). The soluble sodium percent values for the dry season sampling campaign range from 9.99% – 59.06% (average 37.95%) while for the rainy season sampling period the sodium percent vary between 17.2% and 67.90% (average 39.48%). This indicates low alkali hazards and reasonable to excellent irrigation quality (Wilcox, 1950).

Total Dissolved Solids (TDS)

Salts of calcium, magnesium, sodium and potassium existing in the irrigation water may be injurious to plants. When present in severe quantities, they diminish the osmotic actions of the plants and could avert sufficient aeration. The TDS values vary from 10 – 520 mg/l (average 123.5 mg/l) and 10 – 923 mg/l (average 224 mg/l), for both the dry season and rainy season sampling periods respectively. The water can be categorized as exceptional irrigation water according to the determined values in Tables 1 and 2.

Sodium Adsorption Ratio (SAR)

The Sodium adsorption ratio provides a comprehensible indication about the adsorption of sodium by soil. It is the quantity of sodium to magnesium and calcium which have an effect on the availability of the water to the plants. The sodium adsorption ratio of water samples from the dry and rainy season samples ranged from 0.05 – 0.44 (average 0.22) and 0.07 – 4.20 (average 1.23) respectively (Tables 1 and 2). The samples drop under the group of C1-S1 and C1-S2, signifying little alkali hazards and superb irrigation water (Figures 3, 4, 5 and 6), except one sample in the dry season and two samples in the rainy season that showed high salinity hazard.The observed wide range and high deviation as contained in Tables 1 and 2 is an indication that the groundwater quality in the area is skewed by many factors. The TDS, EC and TH display reasonable variation which suggests that the contaminants are from different sources.

Table 1: Statistical summary of concentration of different indices for rating water for irrigation Purposes (Dry Season)

Parameters	Minimum	Maximum	Mean	Stand. Deviation
SAR	0.054	0.437	0.222	0.104
SSP (%)	9.990	59.058	37.947	9.994
RSBC (meq/l)	-1.569	1.142	0.313	0.557
PI (%)	44.525	371.411	119.310	59.831
TH (mg/l)	2.583	253.167	62.567	57.111
MAR (%)	6.722	60.161	32.210	12.175
KR (meq/l)	0.327	2.359	1.106	0.418
TDS (mg/l)	10.000	520.000	123.500	117.440
EC (µS/cm)	10.000	800.000	191.280	0.182

Table 2: Statistical summary of concentration of different indices for rating water for irrigation Purposes (Rainy Season)

Parameters	Minimum	Maximum	Mean	Stand. Deviation
SAR	0.070	4.201	1.238	1.128
SSP (%)	17.219	67.900	39.485	15.368
RSBC (meq/l)	-2.034	1.136	0.058	0.728
PI (%)	14.717	208.847	72.674	58.428
TH (mg/l)	4.250	439.583	82.320	101.029
MAR (%)	9.708	49.918	33.462	11.518
KR (meq/l)	0.095	1.795	0.616	0.478
TDS (mg/l)	6.500	923.000	224.325	39.706
EC (µS/cm)	10.000	1420.000	300.500	351.395

Table 3: Categorization and Suitability of water for Irrigation

Category	EC (µS/m)	RSBC (meq/l)	SAR	SSP (%)	Suitability for irrigation
I	< 117.5	<1.25	<10	<20	Excellent
II	117.5 – 503.61	1.25 – 2.5	10 – 18	20 – 40	Good
III	>503.61	>2.5	18 – 26	40 – 80	Fair
IV	Nil	Nil	>26	>80	Poor

Source: Ayers and Wescot, 1985; Wilcox, 1950

Table 4: Classification of water for irrigation based on TDS

Classification	Total Dissolved Solids (mg/l)	Remark
Non-saline	< 1000	All the Samples
Slightly saline	1000 – 3000	None
Moderately saline	3000 – 10,000	None
Very saline	>10,000	None

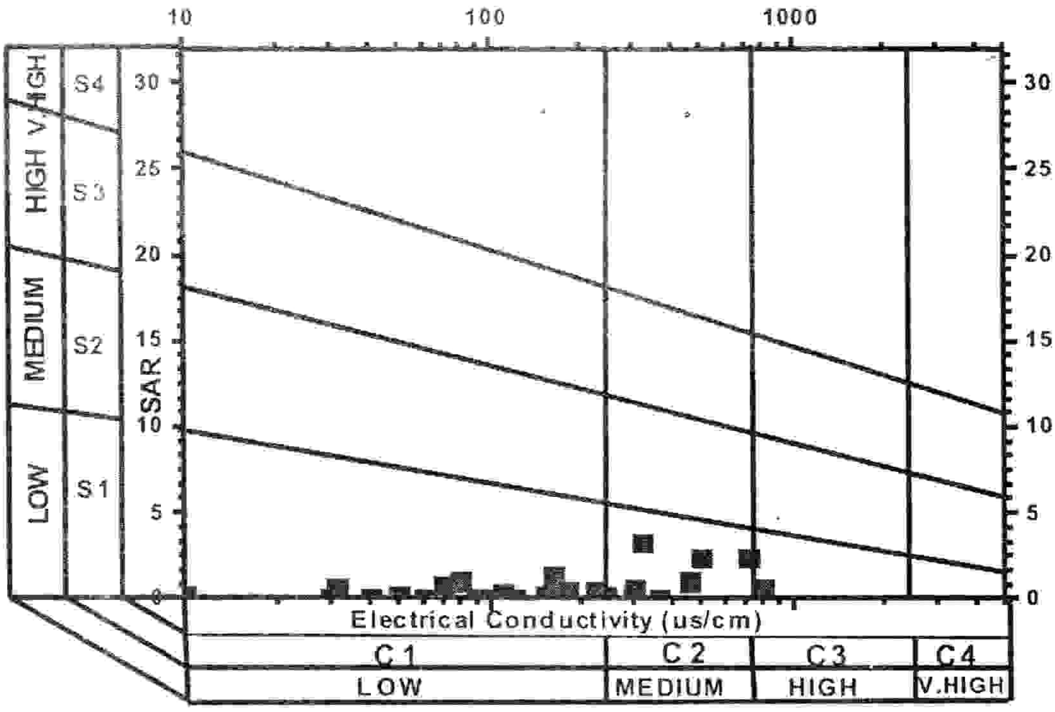

Fig. 3: Salinity hazard diagram for dry season

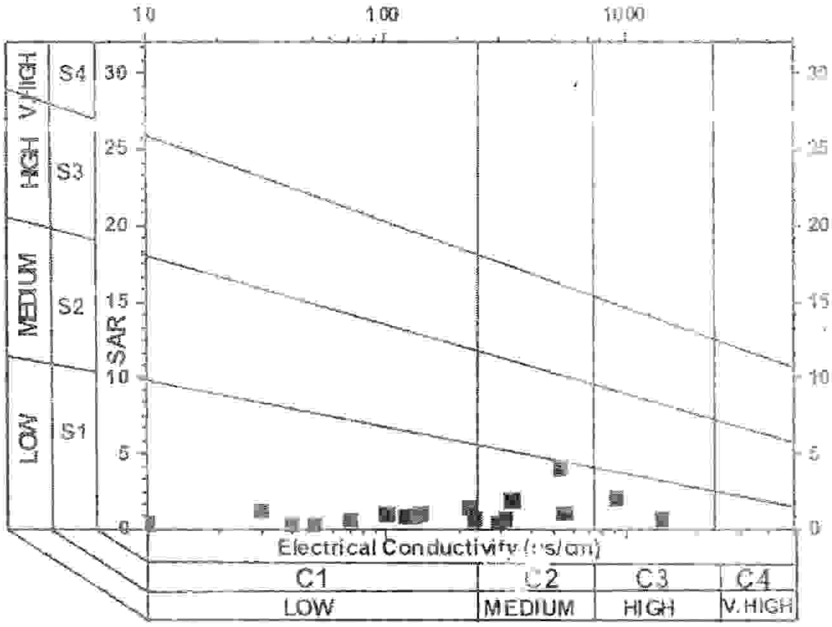

Fig. 4: Salinity hazard diagram for rainy season

From the salinity hazard diagram: S1, S2, S3 and S4 represent low, medium, high and very high sodium (alkali) hazard while C1, C2, C3 and C4 implies low, medium, high and very high salinity hazard. The logical data delineated on the EC versus SAR exemplify that most of the groundwater samples fall mainly in the field of C1-S1 and C2-S1 (Figure 3) for the dry season sampling, indicating low to medium salinity and low sodium water, which may be utilized for irrigation on nearly all kinds of soil with no risk of moveable sodium (Karanth, 1989). Similar trend was observed in figure 4 (rainy season sampling) except a few samples, about 10.5% of the total samples analyzed falls in the C3 field, which implies that the groundwater in these locations can be utilized for irrigation on virtually all kinds of soil with lesser risk of exchangeable sodium (Okiongbo and Dauglas, 2013). None of the samples fall in the area of uncertain (C4-S3) and unsuitable (C4-S4) region for irrigation.

Magnesium Adsorption Ratio

Magnesium concentration in water is regarded as one of the most significant qualitative condition in determining the quality of water for irrigation. In general, calcium and magnesium retain a state of steadiness in nearly all waters. Additional magnesium in water will unfavorably have an effect on crop produced as the soils happen to be more saline (Joshi *et al.*, 2009). The magnesium adsorption ratio calculated for water samples collected in the dry season were within the range of 6.72 % to 60.16 % (average 32.21 %) while the values for water samples collected in the rainy season vary between 9.71 % and 49.91 % (average 33.46 %), with only 3 (average 7.5 %) of the dry season samples having values beyond the conventional limit of 50% (Ayers and Westcot, 1985). The high magnesium adsorption ratio triggers damaging effects to soil when the value is higher than the permissible limit of 50%.

Residual Sodium Bicarbonate (RSBC)

The concentration of bicarbonate and carbonate affects the appropriateness of water for the purpose of irrigation. The water with high RSBC has high pH. Hence, land irrigated with such water happens to be unproductive owing to deposition of sodium carbonate (Eaton, 1950). The remaining sodium carbonate values for water samples collected in the dry and rainy seasons range from -1.57 – 1.14 meq/l (average 0.31 meq/l) and -2.03 – 1.14 meq/l (average 0.058 meq/l) respectively (Tables 1 and 2). The remaining sodium bicarbonate usefulness are less than 2.5meq/l and the water is adjudged safe for irrigation purposes (Figs 5 and 6).

Permeability Index (PI)

The soil permeability is influenced by the long-standing use of irrigated water and the influencing components are the total dissolved solids, sodium bicarbonate and the soil type. For water samples collected in the dry and rainy seasons, the permeability index values range from 44.53 – 371.41% (average 119.31%) and 14.72 – 208.84% (average 72.67%) respectively as contained in Tables 1 and 2. The results therefore indicate that most of the water samples fall in the region of Class I and Class II, and can be classified as good irrigation water (Doneen, 1964)

Kelly's Ratio (KR)

The Kelly's Ratio (KR) values of water samples for the dry season sampling campaign vary between 0.33 and 2.36% (average 1.12%) while those for the rainy season period range from 0.095 - 1.79% (average 0.61%) and shown in Tables 1 and 2 respectively. A quarter of the samples collected in the dry season have KR values above but close to the permissible limit while two samples (Gaduwa and Rubochi) collected in the rainy season have KR values above but close to the permissible limit. Most of the groundwater samples fall in the region of the tolerable limit of 1.0% and are therefore deemed appropriate for irrigation purposes (Table 3). The chemical wear down of rock-forming minerals is the major determinant in the development of chemical constituent of groundwater in the study area.

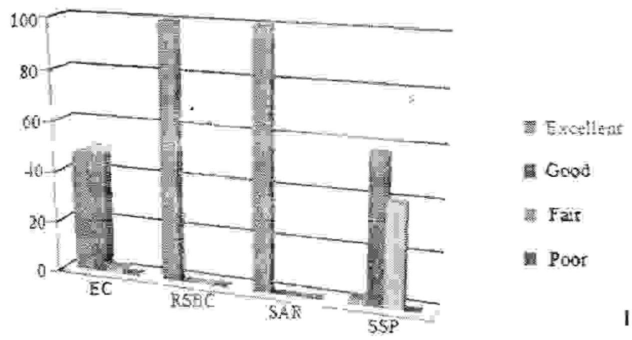

Fig. 5: Irrigation Index Rating for Dry Season

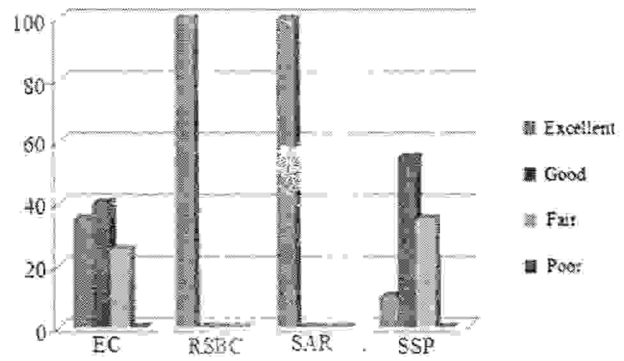

Fig. 6: irrigation Rating for rainy season

Nitrate

The concentrations of the major ions were detected to be lower than their respective maximum permissible limits put forward by World Health Organization and Nigerian Standard for Drinking Water Quality except nitrate whose concentration in some locations exceeds the recommended 50 mg/l. High nitrate content in water for domestic uses causes infant methaemoglobinaemia , also known as blue-baby syndrome, in addition to gastric cancer, metabolic malady and livestock poisoning. The high nitrate content in the shallow groundwater from the area may be credited to the intense metropolitan overflow and high speed of permeation of leachate through the overburden into the perched superficial aquifers in the area that are recorded for the period of the rainy season. The average concentration of total dissolved solids (TDS) and electrical conductivity (EC) were also higher in rainy season equated to the dry season as experienced previously, which is also credited to metropolitan overflow and or dissolution of rock layer in the course of groundwater movement.

Conclusion

The quality of grour dwater from Abuja has been assessed for irrigational purposes in this study. The facies analyses indicate that the groundwater in the area is of alkaline (bicarbonate-type). The electrical conductivity values and the total dissolved solids values of the groundwater samples were within the acceptable limit during the dry season sampling but with higher values during the rainy season sampling. This can be attributed to rock-water interaction resulting in chemical weathering and dissolution, triggered by rain-water, as more ions were dissolved in the course of infiltration and groundwater movement thereby enriching the groundwater composition. On the basis of the quality parameters examined such as SAR, SSP, MAR, RSBC, PI and KR, the appropriateness of groundwater samples for irrigation is in the ratio of good to excellent (93%) and poor to fair (7%). About 93% of the plotting in the salinity charts falls within the low salinity zone, indicating low sodic water and thus suitable for irrigation purposes, with a very few isolated exceptions (7%). The yearly variation in the results obtained during the three years of investigation was insignificant. This is an indication that the chemistry of the groundwater system in the area is almost constant and the implication is that the groundwater it is free from urban pollution and suitable for irrigation purposes as at the time of the present study.

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