EVALUATION OF GROUNDWATER CHEMISTRY IN PARTS OF ABUJA, NIGERIA USING FACTOR ANALYSIS AND WATER QUALITY INDEX

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ABSTRACT

Water is a universal solvent and natural resource tapped by man, animal and plants to meet their need on earth, either in vapour, liquid or solid form. Due to inadequate supply of pipe-borne water, many house-holds in Abuja, Nigeria's Federal Capital Territory, depend on boreholes and hand-dug wells for their daily water needs, hence the need to ascertain the quality status of groundwater in the area. A total of sixty (60) sets of groundwater samples were collected from two field sampling periods of dry and rainy seasons between the months of April, 2009 and February, 2010. The samples were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) in Actlabs, Canada. The result of the laboratory analysis was transformed using water quality index and factor analysis. Six factors were identified which accounts for 76.70% of the total variance for dry season and 88.53% of the total variance for rainy season. This implies that the groundwater systems in the area are contaminated through six possible sources. The contaminants are from natural sources such as bedrock dissolution and weathering processes while the remaining factors are attributed to anthropogenic activities arising from urbanization such as leachate from dumpsites, soakaways and agro-chemicals. The water quality index shows that the water in the area range from good to poor. Due to food insecurity, undeveloped plots of land are converted to farmland and the agro-chemicals applied on the soils over time infiltrate into the shallow water table in the area. The suggested geogenic and or anthropogenic factors may be responsible for the modification of the groundwater chemistry in the area. Public enlightenment on the good hygiene and danger of groundwater contamination is recommended.

Keywords: Evaluation, Groundwater Chemistry, Factor Analysis, Water Quality Index, Abuja, Nigeria

1. Introduction

Water is a universal solvent and natural resources tapped by man, animal and plants to meet their need on earth, either in vapour, liquid or solid form. Water is one of essential compounds for all forms of plants and animals, thus its pollution is generally considered more important than soil. Studies show that about 80% of communicable diseases are either water-borne or water related.

Water is an indispensable resource for existence of man, animals and plants. Demand for groundwater has been on the increase due to rapid growth in population as well as the accelerated pace of industrialization and urbanization in the last few decades especially in developing countries like Nigeria [1]. The inadequate supply of piped borne water and the paucity of surface water have led to increase in demand for groundwater in Abuja. People around the world have used groundwater as a source of drinking water and even today more than half the world's population depends on ground water for survival. Groundwater has long been considered as one of the purest forms of water available in nature and meets the overall demand for rural and semi-rural people [2]. The increase in groundwater demand for various human activities has placed great importance on water science and management practice world-wide.

2. Research Objectives

The study evaluates the chemistry of groundwater in central part of Abuja, Nigeria for domestic purposes. Due to the upsurge in the population of Abuja, Nigerian Federal Capital Territory, it is necessary to ascertain the suitability of the groundwater for domestic purposes in order to avoid water borne diseases.

3. Statement of the Problem

The poor management of waste arising from industrialization and urbanization has led to contamination of groundwater hence the need for the present study. It therefore becomes imperative to evaluate the quality of groundwater from shallow aquifers in Abuja, in order to prevent the occurrence of water borne diseases such as typhoid, cholera, diarrhea and dysentery as well as cancer related diseases due to contamination by heavy metals

4. Research Methodology

A total of sixty (60) sets of groundwater samples were collected from existing hand-dug wells and boreholes in the area according to [3] method during the dry and rainy seasons between the months of April, 2009 and February, 2010. Plastic containers were used for the collection of the water samples were rinsed with the samples to be collected twice according to [4] method. Field parameters such as electrical conductivity (EC), total dissolved solids (TDS), pH and temperature were determined in the field using HACH KIT digital conductivity meter (Model 44600) for EC and TDS while pH was determined using HANNA pH meter (Model HI 28129). The water temperature was determined using mercury thermometer. The chemical parameters were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) in Actlabs, Canada and they include: calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphates, nitrate, dissolved oxygen, iron, barium, strontium, copper and lead.

4.1. Multivariate Statistical Analysis

The factor analysis (FA) is a multivariate statistical technique employed for the purpose of data reduction with a view to determining the sources of elements and their controlling factors. The FA depends upon the fact that the variables in a data set are usually partially-to-strongly correlated and it transforms that data set into an uncorrelated one, define by a new set of variables known as factor components [5]. The first factor component is such that the projections of the given points onto it have maximum variance, the second factor component has the variance subject to being orthogonal to the first; the third factor component has the maximum variance subject to being orthogonal to the first and second components and so on. The multivariate statistical technique therefore relates variables into principal associations (factors) based on their mutual correlation coefficients and these associations may be interpreted in terms of mineralization, lithology and environmental processes [6]. The application of the analysis has proved useful in the interpretation of hydrogeological data as revealed by many workers [7]. The multivariate analysis was carried out using the statistical package for Social Sciences Software (SPSS).

4.2. Water Quality Index

The Water Quality Index (WQI) was applied in this study. The WQI was calculated from the point of view of suitability of the water for human consumption. The index has been widely used and applied to data from different geographical locations all over the world to calculate water quality for various water bodies. It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers [8]. It thus, becomes an important tool for the assessment and management of surface and groundwater. It provides a single number that expresses the overall quality of water at certain location and time based on several water quality parameters. It expresses complex water quality data into understandable information usable by common people.

A quality rating scale (q_i) for each parameter is assigned by dividing its concentration (C_i) in each water sample by its respective Nigerian Standard for Drinking Water Quality (S_i) and the result multiplied by 100 as shown in the formula: $q_i = (C_i / S_i) \times 100$

The Relative weight (w_i) was obtained by a value inversely proportional to the recommended standard (S_i) of the corresponding parameter according to the equation: $w_i = 1/S_i$

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating (q_i) with unit weight (w_i) linearly.

$$WQI = \sum_{n=1}^{i=n} (q_i w_i)$$

Where:

q_i: the quality of the ith parameter,

w_i: the unit weight of the ith parameter and

n: the number of the parameter considered.

The overall water quality of an area is therefore obtained using the formular:

$$\textit{Overall}\ \mathrm{WQI} = \frac{\sum q_i w_i}{\sum w_i}$$

5. Review of Geology and Hydrogeology of the Study Area

The study area is underlain by porphyritic granite belonging to the Pan African older granites of the Nigerian basement complex. Texturally, they are differentiated into coars and fine grained. Mineralogically, they consist predominantly of quartz, feldspars and mica (Fig. 1). [9] described the contact between the Pan African granites and the host rock as intrusive gradational and replacive while the contact between the older granite suite are both sharp and also gradational. It has also been suggested that the Pan Africa granites are characterized by distinctive layering which are normally aligned parallel to northwest-southeast lineaments [10]. The major deformational feature across the study area is a NW-SE trending fault (Fig. 2). These faults have been interpreted as resulting from trans-current movements. According to [11] borehole yields in the Nigerian basement complex rocks range from 1 l/s to 2 l/s, and up to 4l/s in fractured zones. The static water level of existing hand-dug wells and their coordinates were used to construct the groundwater flow direction for the area (Fig. 3), which also corresponds to NW-SE direction, an indication that it is structurally controlled.

6. Results and Discussion

The statistical summary of the physico-chemical parameters analyzed for both dry and rainy seasons are showed in Table 1. The temperature ranged from 26.82–31.40 °C with a mean value of 29.13 °C and 27.00–30.75 °C with an average value of 28.94 °C (Table 1). It is expected that rainy season temperatures are lower than dry season temperatures. The pH varied from 4.42–7.54 with a mean value of 6.11 for dry season sampling and 4.50–6.70 with an average value of 6.44 for the rainy season sampling (Table 1). The groundwater from the regolith aquifers in the area are acidic as the mean value of both dry and rainy seasons are below the WHO accepted permissible range of 6.50–8.50. Acidic condition enhances chemical weathering and dissolution of host rocks in the course of rock-water interaction as well as mobility of metals [12]. The pH concentration maps for dry and rainy seasons are shown in figure 4. for The electrical conductivity (EC) ranged between 10.86–800.50 µs/cm and an average value of 191.28 µs/cm during the dry season while in the rainy season, it ranged from 10.00–1420.00 µs/cm and a mean value of 314.52 µs/cm. Similarly, the value of total dissolved solids (TDS) varied from 10.45–520.45 mg/L with a mean value of 123.54 mg/L for dry season and 10.00–920.00 mg/L with an average value of 224.60 mg/L for the rainy season (Table 1).

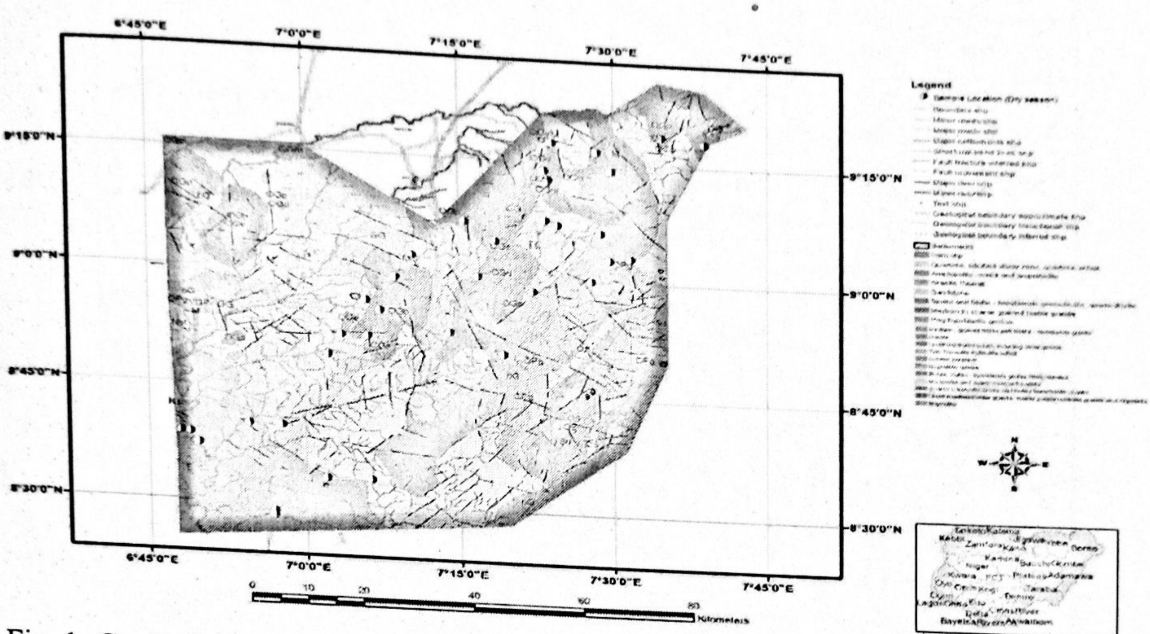

Fig. 1: Geological map of Abuja, showing sample locations (Modified from NGSA, 2004)

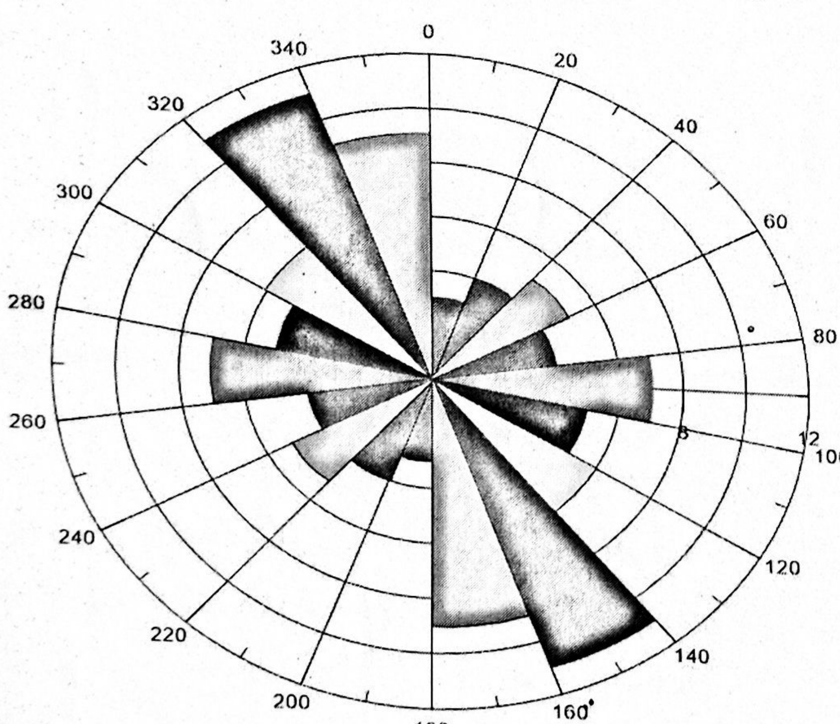

Fig. 2: Rosset diagram show the principal fracture direction in the area

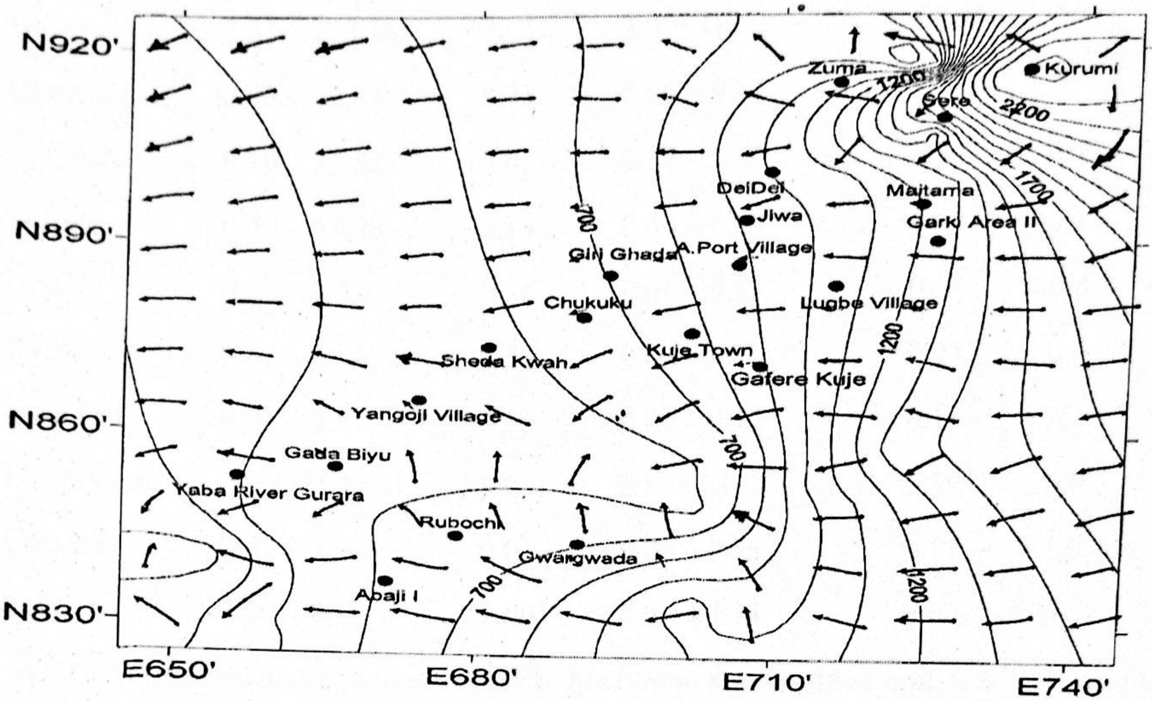

Fig. 3: Groundwater flow direction for the area

Table 1 Statistical Summary of Dry and Rainy Seasons results of Groundwater in Abuja

Parameters	Dry Season Sampling		Rainy Season Sampling		WHO, (2010)
(mg/l)	Range	Mean	Range	Mean	MPL
Temp. °C	26.82 – 31.40	29.13	27.0–30.75	28.94	Ambient
pH	4.42 – 7.54	6.11	4.5 – 6.7	6.44	6.5 – 8.5
EC µS/cm	10.86 – 800.50	191.28	10. – 1420	314.52	1000
TDS,	10.45 – 520.45	123.54	10 – 920	224.60	500
Calcium	1.30 – 70.42	17.98	1.2 – 106	22.31	200
Magnesium	0.24 – 23.80	4.66	0.3 – 41.9	8.73	200
Sodium	1.35 – 40.92	11.42	1.5 – 65.8	20.11	200
Potassium	1.10 – 71.25	7.08	0.4 – 52.4	52.48	50

Bicarbonate	2.02 – 223.18	72.41	2.0 – 317	72.56	100
Chloride	0.06 – 63.83	8.31	0.06 – 93.2	22.35	250
Sulphate	0.10 – 35.52	2.45	0.17 – 57.5	6.37	100
Nitrate	0.30 – 33.98	5.14	0.40 – 63.9	14.43	50
Iron	0.01 – 3.72	0.36	0.01 – 0.53	0.11	0.3
Barium	0.02 – 0.54	0.23	0.02 –0.87	0.24	0.7
Strontium	0.01 – 2.31	0.26	0.01 – 0.77	0.18	NA
D. Oxygen	2.0 1– 7.45	5.04	2.8 – 8.3	5.39	6.0
Copper	0.01 – 0.15	0.03	0.00 – 0.25	0.11	1.0
Lead	0.00 – 0.01	0.001	0.0 – 0.014	0.002	0.01

WHO: World Health Organization, MPL: Maximum Permissible Limit, NA: Not Applicable

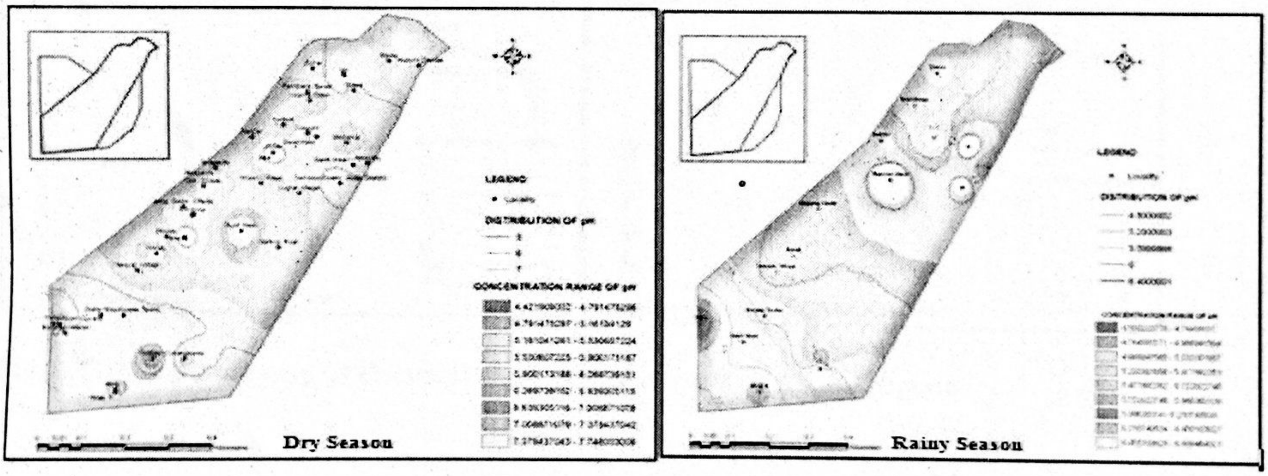

Fig. 4: pH concentration map of parts of Abuja, Nigeria

During the rainy season, the values of EC and TDS in some locations are higher than their respective maximum allowable value of 1000 μs/cm and 500 mg/L [12]. The pH, EC and TDS are good indicators of water quality in any location. The implication is that groundwater system in the area contained some dissolved ions, which may be attributed to the dilution effect of rainfall. Also, the rain carries a lot of weathered and dissolved ions precipitated by the acidic condition leading to high run-off and subsequent infiltration into the underlying shallow regolith aquifer and the groundwater is enriched by ions. The EC and TDS concentration maps of Abuja are illustrated in figures 5 and 6 respectively. The concentration of the major cations (calcium, magnesium, sodium and potassium) in both seasons falls below their individual maximum permissible limits which suggest the groundwater in the area is not contaminated by these elements. The concentration of the chloride and sulphates were found to below the permissible limit of 250 mg/L and 100 mg/L respectively. However, the concentration of bicarbonate (2.02–223.18 mg/L) for dry season and (2.00–317.00 mg/L) for rainy season as well as nitrate (0.40–63.90 mg/L) for rainy season exceeds the permissible value of 100 mg/L for bicarbonate and 50 mg/L for nitrate (Table 1). Bicarbonate concentration map was superimposed on the geology map the area (Fig. 7) since its enrichment in the groundwater system is by geogenic processes. High nitrate content in water causes cyanosis and asphyxia (blue-baby syndrome), a disease in infants below 3 months [13]. Groundwater contamination by nitrate may be due to urbanization as a result of fertilizer application or leachates from unlined dumpsites and soakaway [14]. The high value of bicarbonate has no known health impact and is characteristic of a typical shallow groundwater from a basement aquifer [15, 16].

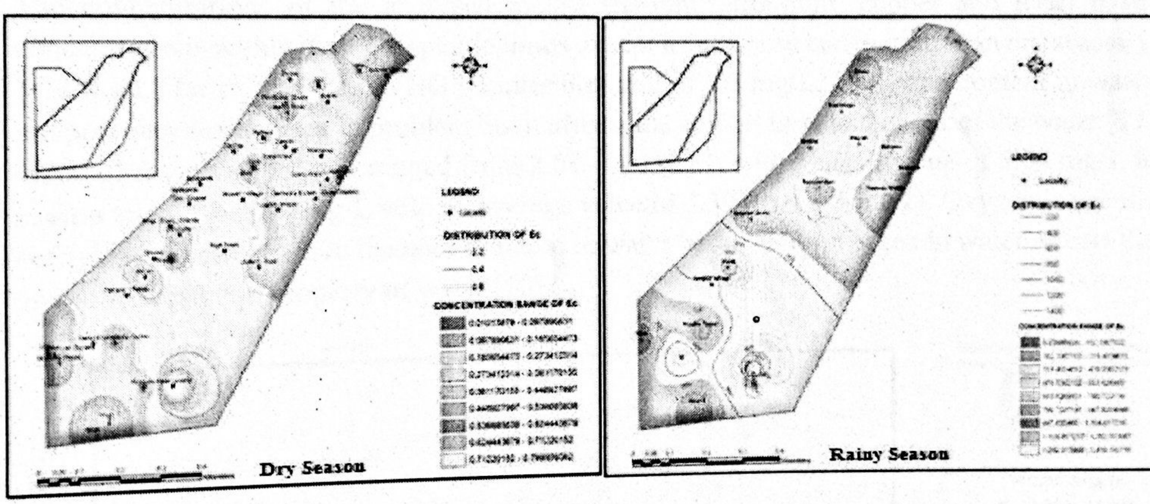

Fig.5: Concentration map of electrical conductivity of parts of Abuja, Nigeria

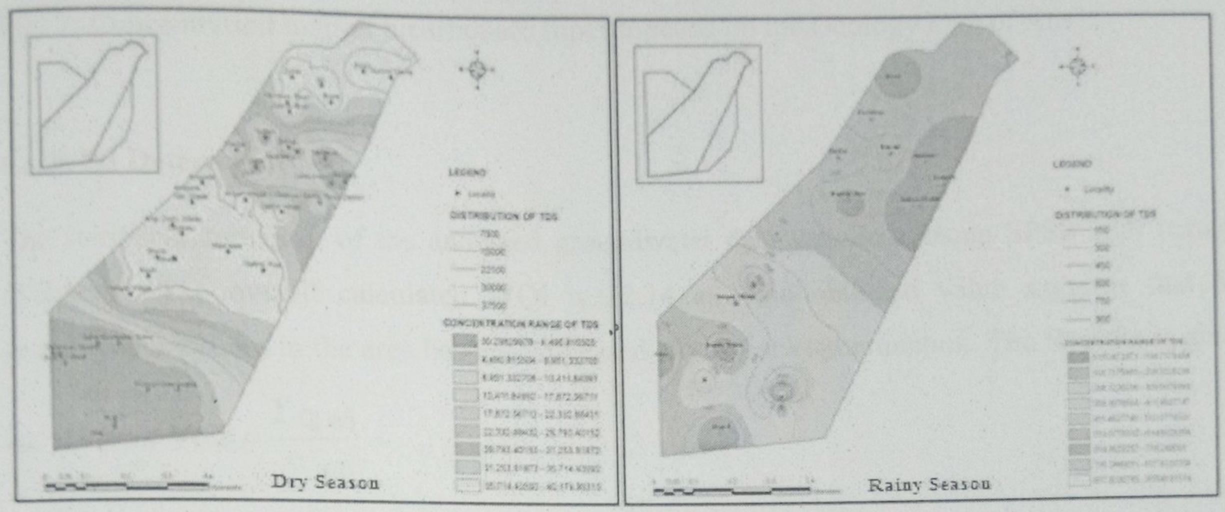

Fig. 6: Concentration map of TDS of parts of Abuja, Nigeria

The concentrations of the analyzed metals (barium, strontium, copper and lead) have their concentrations within their acceptable limits except iron, whose concentration in dry season (0.30–3.72 mg/L) far exceeds the WHO permissible limit of 0.3 mg/L. High iron content in water does not pose any serious health problem but it affects the colour, taste and odour of the water [17]. The value of dissolved oxygen ranged from 2.01–7.45 mg/L with a mean value of 5.04 mg/L for dry season and 2.80–8.30 mg/L with an average value of 5.39 mg/L (Table 1). Oxygen is necessary in sufficient quantity to give the taste required in water because low oxygen in water affects the taste and other aesthetic property of water [18].

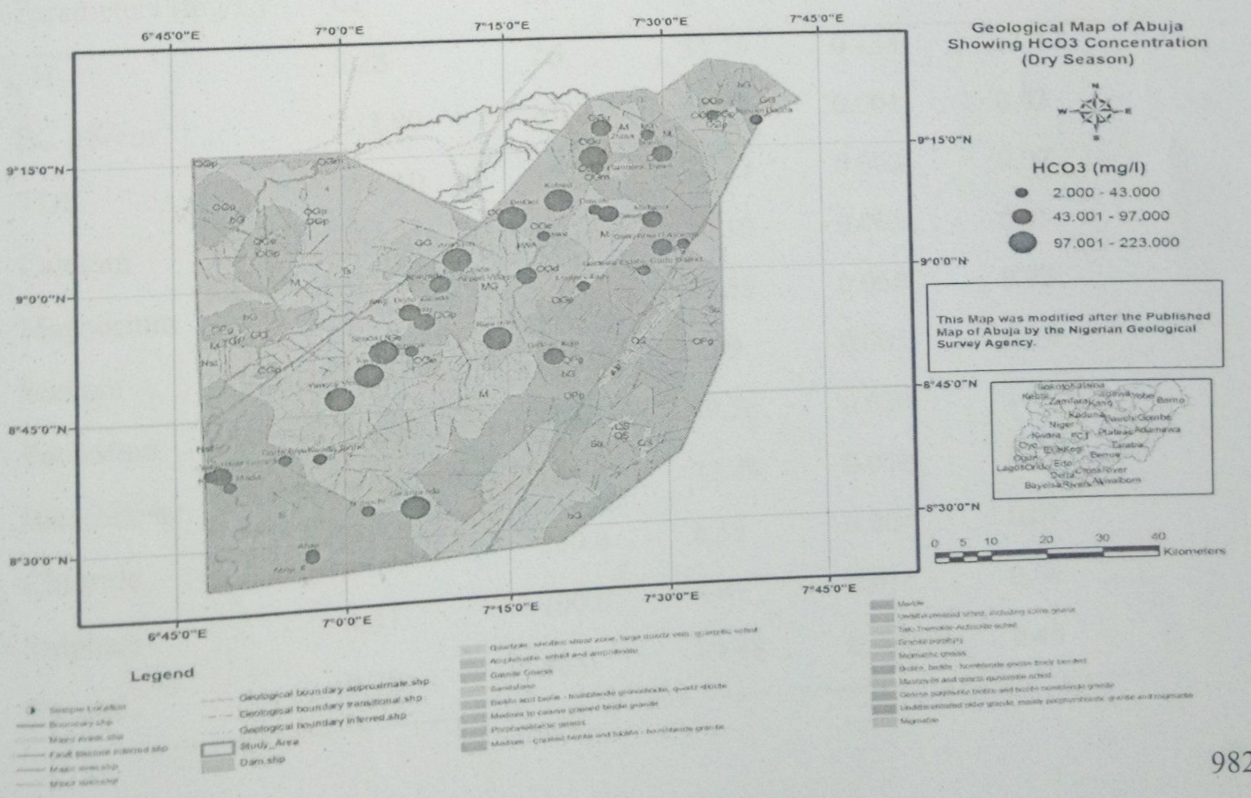

Fig. 7: Concentration map of bicarbonate superimposed on the Geology map of Abuja

6.1 WQI Determination

The statistical summary of the analyzed groundwater data was done using SPSS 12.0 version (Table 2). The overall calculated WQI is 22.14 and the obtained value suggests that the groundwater system in the area has not witnessed any major contamination. The formula is given as: $Overall\ WQI = \frac{\sum q_i w_i}{\sum w_i}$

Where: q_i: the quality of the ith parameter,

w_i: the unit weight of the ith parameter

$$Overall\ WQI = \frac{\sum q_i w_i}{\sum w_i} = \frac{2350.69}{106.19} = 22.14$$

Table 2: Computed Water Quality Index parameters

Parameters (mg/L)	*Ci*	*Si*	*Qi*	*Wi*	*QiWi*
pH	6.28	7.5	83.70	0.133	11.13
EC µS/cm	252.90	1000.0	25.30	0.001	0.03
TDS	174.10	500.0	34.80	0.002	0.07
Calcium	20.15	200.0	10.10	0.005	0.05
Magnesium	6.70	20.0	33.50	0.050	0.02
Sodium	15.77	200.0	7.89	0.005	0.04
Potassium	29.78	50.0	59.56	0.020	1.19
Bicarbonate	72.49	100.0	72.49	0.010	0.72
Chloride	15.33	250.0	6.13	0.004	0.02
Sulphate	4.41	100.0	4.41	0.010	0.04
Nitrate	9.79	50.0	19.58	0.020	0.40

Iron	0.24	0.3	80.00	3.333	266.40
Barium	0.23	0.7	34.30	1.430	49.05
D. Oxygen	5.22	6.0	87.00	0.167	14.53
Copper	0.07	1.0	7.00	1.000	7.00
Lead	0.002	0.01	20.00	100.0	2000.00

6.2 Factor Analysis

The varimax rotated factor loading for groundwater chemistry in the dry season is contained in Table 3. A total of six factors were adjudged responsible for the chemistry of groundwater in the area which accounts for 84.69% of the total variance (Table 3). In factor extraction, the impact of factors with Eigen values greater than one are considered significant contributors to the overall pollution process of the groundwater system while those with Eigen values less than are adjudged insignificant and their impact negligible to the whole pollution process and therefore not considered [19]. **Factor-1** has the highest loading of 29.59% and the contributors includes calcium, bicarbonate, magnesium, sodium, sulphate and potassium. The presence of these major ions are due to bedrock dissolution arising from rock-water interaction. **Factor-2** explains 18.92% of the total variance and includes alkalinity, chloride, fluoride, silica and phosphorous and their presence in the groundwater may be attributed to weathering of host rock.

Contributors of factors 1 and 2 are natural processes arising from the local geology of the area. Apart from the geogenic attribute, high chloride and sulphates ion in water may be attributed to urban pollution [20]. **Factor-3** has a moderate loading from Aluminum, iron, nitrate, phosphate and it accounts for 13.18% of the total variance. The area is characterized by a low pH (Table 1) and this encourages chemical weathering leading to enrichment of the groundwater facies with major ions as evidenced in factors 1 and 2 as well as the formation of laterites which are composed chiefly of iron and aluminum oxides. The presence of iron in lateritic soils is responsible for the reddish-brown or yellow colour of the soil.

Table 3: Varimax rotated factor loading for dry season groundwater chemistry in parts of Abuja

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Calcium	**.944**	.046	.001	-.047	.103	.020
Alkalinity	.257	**.701**	.199	.156	-.002	.055
Bicarbonate	**.857**	-.401	.199	.156	-.002	.055

Magnesium	**.810**	.150	.229	.110	-.112	.090
Sodium	**.773**	.046	-.356	-.290	.332	-.062
Sulphate	**.734**	.283	.250	.438	-.288	.003
Potassium	**.702**	.369	.245	.441	-.238	.000
Chloride	.306	**.602**	.337	-.281	.237	-.076
Flouride	.478	**.734**	.133	-.186	.081	.028
Nitrate	.264	.107	**.673**	-.133	.078	-.018
Silica	.414	**.706**	-.346	.041	.261	.127
Barium	.334	.241	-.064	**.593**	.319	.030
Manganese	.324	-.580	.387	-.376	.105	**.541**
Phosphorous	.095	-.121	**.737**	.128	.140	-.036
Phosphate	-.029	**.566**	.282	.404	.074	-.145
Aluminium	-.191	.164	**.523**	.357	.394	-.286
Iron	-.314	.229	**.644**	.158	.321	-.364
Lead	-.230	.042	.245	.381	.224	**.502**
Bromide	.037	.192	-.164	**.592**	-.292	.206
Copper	-.239	.092	.135	.102	**.659**	.134
Strontium	-.342	.290	-.103	**.598**	.238	.115
Zinc	-.115	.170	.065	.214	**.623**	.253
Eigen values	6.214	4.344	3.347	2.757	1.945	1.098
% of Variance	29.593	18.924	13.177	10.368	7.403	5.229
Cummulative %	29.593	48.517	61.694	72.062	79.465	84.694

The iron in the laterite gets to water-table through infiltration and leaching processes. Similarly, nitrate and phosphate may be coming from the use of fertilizer used in farming. **Factor-4** accounts for 10.37% of the total variance with copper and zinc as the contributing factor while **Factor-5** explains 7.40% of the total variance and loading coming from lead and manganese. **Factor-6** has the lowest loading of about 5.23% due to bromide and strontium enrichment. Contributors to factors 3 to 6 are from both anthropogenic interference such as urbanization (leachate from agrochemicals, dumpsites and soakaways) as well as geogenic means via bedrock dissolution and chemical weathering of mafic and ultramafic rocks.

Similarly, the varimax rotated factor loading for groundwater chemistry in the rainy season is shown in Table 4. Also, a total of six factors were obtained which implies six possible sources of pollution to the groundwater system in the area. They six factor account for 90.53% of the total variance (Table 4). **Factor-1** has the highest loading of 32.05% and the contributors include Potassium, Magnesium, Calcium, Alkalinity, Bicarbanate and Bromide. These ions are released into the groundwater through dissolution of the bedrock. The major ions (calcium, magnesium, potassium and sodium) are as a result of the dissolution and hydrolysis of silicate minerals during water-rock interaction **Factor-2** explains about 20.34% of the total variance with loading from phosphate, strontium, nitrate, sulphate and chloride. The presence of these ions in the groundwater can be attributed to the chemical weathering of mafic and ultra-mafic minerals and are enhanced by run-off and infiltration processes.

Factor-3 has a moderate loading from manganese, sodium, phosphorous and barium which accounts for 14.89% of the total variance. The natural processes arising from rock-water interaction influence their enrichment in the groundwater regime. **Factor-4** accounts for 11.30% of the total variance with silicon, flouride, aluminum and iron as contributing factor. The silicon enrichment in the groundwater is related to the dissolution of soluble minerals in the bedrock leaving the more resistant silica. Iron and aluminum dissociation from bedrock through weathering enhanced by low pH, may be is responsible for the formation of lateritic soils as iron is responsible for the reddish-brown or yellow nature of the soil.

Table 4:Varimax rotated factor loading for rainy season groundwater chemistry in parts of Abuja

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Sodium	.331	.343	**.857**	-.042	-.101	-.038
Potassium	**.956**	.150	.138	-.064	-.102	-.024
Magnesium	**.943**	.180	.000	.094	-.051	-.153
Calcium	**.937**	.292	.042	.143	-.060	-.044
Manganese	.064	-.249	.213	.026	-.116	**.542**
Iron	-.101	-.112	-.184	**.543**	.262	.090
Copper	.122	.306	.008	-.163	**.555**	.014
Lead	-.063	.042	-.065	-.017	.000	**.887**
Zinc	-.045	.033	-.043	.057	**.967**	-.111
Silicon	-.108	-.042	-.078	**.943**	.056	.100
Barium	.294	.392	**.567**	-.186	-.113	-.229

Aluminium	-.154	-.215	-.308	**.585**	-.163	**.557**
Phosphorous	.064	-.052	**.640**	.372	-.125	.489
Strontium	.270	**.710**	.054	.052	-.104	-.069
Chloride	.356	**.602**	.462	-.155	.197	-.069
Bromide	**.841**	.209	.361	-.121	.157	-.009
Flouride	.440	-.090	-.168	**.728**	-275	-.068
Nitrate	.216	**.677**	.108	-.082	.179	-.091
Phosphate	-.012	**.800**	-.018	.345	-176	.096
Sulphate	.468	**.712**	.047	-.039	-.101	.031
Alkalinity	**.866**	-.175	.242	.331	-.131	.050
Bicarbonate	**.866**	-.175	.242	.331	-.131	.050
Eigenvalues	9.251	5.934	3.395	2.047	1.791	1.059
% of Variance	32.050	20.335	14.888	11.303	7.140	4.812
Cummulative %	32.050	52.385	67.273	78.576	85.716	90.528

Factor-5 explains 8.14% and is attributed to loadings from copper and zinc while **Factor-6** has the lowest loading of about 4.81%, contributed by lead and manganese. Leachate from metallic objects littered in most parts of the city and agrochemicals finds their way into the groundwater especially during the rainy season when infiltration is high.

6.3 Hydrochemical Facies Determination by Schoeller Plot

The semi-logarithmic plot was developed by Schoeller to represent major ion analyses in meq/L and to demonstrate different hydrochemical water types on the same diagram (Fig. 8). The type of graphical representation has the potential of determining the water type in area. The actual concentrations of each parameter are plotted and compared. From the Schoeller plot, the water type in the area is calcium-bicarbonate type.

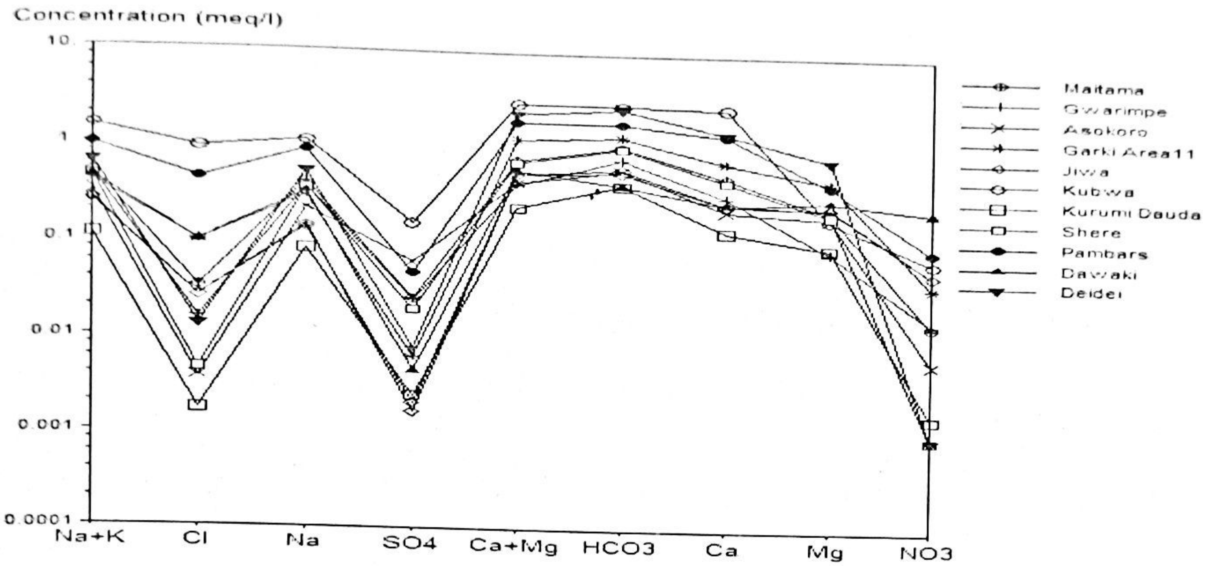

Fig. 8: Schoeller plot of parts of Abuja, Nigeria

7. Conclusion and Recommendation

The water quality in the central part of Abuja was investigated in the present study through water quality index and factor analysis. The results of the WQI showed that the groundwater in central part of Abuja fairly good for domestic uses. Six factors were identified by factor analysis which corresponds to six possible sources of contamination to the groundwater regime in the area. These contributors are both geogenic and anthropogenic. The Ca-HCO3 water type dominates groundwater system in the study area. The major processes controlling the groundwater chemistry in the area include: chemical weathering, dedrock dissolution, ionic exchange, oxidation process, fertilizer application, poor on-site sanitation and urbanization. Public awareness campaign on the dangers of groundwater contamination is encouraged.

6. Reference

[1]. Abimbola, A. F., Odukoya, A. M. and Olatunji, A. S. (2002). Influence of bedrock on the hydrogeochemical characteristics of groundwater in Northern part of Ibadan metropolis, SW Nigeria. *Water Resources Journal, 9*, 195-202.

[2]. Amadi, A. N., Yisa, J., Ogbonnaya, I. C., Dan-Hassan, M. A., Jacob, J. O. & Alkali, Y. B. (2012). Quality evaluation of River Chanchaga using Metal Pollution Index and Principal Component Analysis. *Journal of Geography and Geology,* 4(2), 13-21.doi:10.5539/jgg.v4n2p13.

[3]. APHA (2008). *Standard methods for examination of water and waste water*, (20th Ed.). Washington DC: American Public Health Association.

[4]. Amadi A. N., Dan-Hassan M. A., Okoye N. O., Ejiofor I. C. & Aminu T. (2013). Studies on Pollution Hazards of Shallow Hand-Dug Wells in Erena and Environs, North-Central Nigeria. *Environment and Natural Resources Research*, 3(2), 69-77. doi:10.5539/enrr.v3n2p69.

[5]. Amadi, A. N., Olasehinde, P. I. & Nwankwoala, H. O. (2014). Hydrogeochemistry and statistical analysis of Benin Formation in Eastern Niger Delta, Nigeria. *International Research Journal of Pure and Applied Chemistry*, 4(3), 327-338.

[6]. Olasehinde, P. I., Amadi A. N., Dan-Hassan M. A. & Jimoh M. O. (2015a). Statistical Assessment of Groundwater Quality in Ogbomosho, Southwest Nigeria. *American Journal of Mining and Metallurgy*, 3(1), 21-28, doi:10.12691/ajmm-3-1-4.

[7]. Dan-Hassan, M. A., Olasehinde, P. I., Amadi, A. N., Yisa, J. & Jacob, J. O. (2012). Spatial and temporal distribution of nitrate pollution in Groundwater of Abuja, Nigeria. *International Journal of Chemistry*, 4(3), 104-112, doi: 10.5539/ijc.v4n3p104.

[8]. Amadi, A. N. (2011). Assessing the Effects of Aladimma Dumpsite on Soil and Groundwater Using Water Quality Index and Factor Analysis. *Australian Journal of Basic and Applied Sciences*, 5(11), 763-770.

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

[10]. Obaje, N. G. (2009). *Updates on Geology and Mineral Resources of Nigeria*. Onaivi Printing and Publishing Co LTD, Abuja, Nigeria, 213p.

[11]. Ajibade, A. C. (1982). The origin of the Older Granites of Nigeria: some evidence from the Zungeru region. *Nigerian Journal of Mining and Geology*, 19(1), 223-230.

[12] Okunlola, I. A., Amadi, A. N., Onyemere, U. B. & Okoye, N. O. (2015). Quality Assessment of Surface and Groundwater Sources in Lugbe, Abuja, North-Central Nigeria. *Journal of Environment and Earth Science*, 5(8), 129 – 139.

[13]. Amadi, A. N., Soliu, A. A., Agwuncha, S. C., Nwankwoala, H. O., Nwakife, C. N. & Shaibu I. (2016). Analytical Studies on Surface and Groundwater in Zungeru, Niger State, North-central Nigeria. *Development Journal of Science and Technology Research. In Press.*

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

[15]. World Health Organization (2008). *Guidelines, for drinking water quality*. First addendum to the Third Edition Volume 1. Recommendation, pp. 491- 493.

[16]. Amadi, A.N., Aminu, T., Okunlola, I. A., Olasehinde, P. I. & 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.

[17]. Prasad, B. & Narayama, S. (2004). Heavy metal pollution index of ground water of an abandoned open cast mine filled of the water quality of River Adyar, India. *Bulletin of Environmental Contamination and Toxicology*, 82(2), 211-217.

[18]. Yisa, J. & Jimoh, T. (2010). Analytical studies on water Quality Index of River Lavu, Bida, North-central Nigeria. *American Journal of Applied Sciences*, 7(4), 453-458

[19]. Olasehinde P. I., Amadi A. N., Dan-Hassan M. A. & Jimoh M. O. (2015b). Statistical Assessment of Groundwater Quality in Ogbomosho, Southwest Nigeria. *American Journal of Mining and Metallurgy*, 3(1), 21-28, doi:10.12691/ajmm-3-1-4.

[20]. Okunlola, I. A., Amadi, A. N., Olashinde, P. I., Maspalma, S. S. & Okoye, N. O. (2016). Quality Assessment of Groundwater from Shallow Aquifers in Hong Area, Adamawa State, Northeastern Nigeria. *Ife Journal of Science,* 18(1), 267-283.