# HYDROGEOCHEMICAL CHARACTERISATION OF GROUNDWATER RESOURCES IN FCT, ABUJA, NORTHCENTRAL NIGERIA

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***ABSTRACT***
*This paper examined the influence of geology on the groundwater quality in the Federal Capital Territory, Abuja, Nigeria. The work involved the study of fifty (50) groundwater samples collected by the National Water Resources Institute, Kaduna across the six Area Councils during its "Assessment of Drinking Water Quality in Federal Capital Territory (FCT)" in 2016. The result of the analysis of each sample was discussed in terms of the rock type that forms the aquifer which enabled the characterisation of the hydrogeochemical facies of the groundwater and the mechanism controlling its quality. The potential health risks associated with ingesting heavy metals in water were determined. The main hydrogeochemical facies is the mixed type of Ca-Mg-Cl and Na-$HCO_3$-Cl with none of the cation-anion pair being dominant in the groundwater. The dominant mechanism controlling the quality of groundwater in the study area is rock weathering followed by the chemistry of rainwater. The hazard index ranges in value between 0.0 and 0.6. Since the maximum value is less than 1, the ingestion of the groundwater in the study area poses no significant risk of non-carcinogenic effect to the consumers.*

***KEYWORDS:*** *FCT, groundwater quality, hydrogeochemical facies, heavy metals, health risks*

## 1.0 INTRODUCTION

Water quality is a global environmental issue and it involves a large number of physico-chemical parameters such as heavy metals, cations and anions present in water. It is a measure of the suitability of water in relation to human need and purpose. Indiscriminate use of chemical fertilisers, pesticides, improper disposal of wastes and industrial effluents, as well as leachate from landfills can negatively impact groundwater quality.The Federal Capital Territory (FCT), Abuja, is the political and administrative headquarters of Nigeriaand is made up of six Area Councils with a rapidly growing population. The FCT Water Board is responsible for water supply from surface water sources to some satellite and major towns while the rural and suburban areas depend mostly on groundwater sources through boreholes and hand-dug wells. These groundwater sources are developed and owned by private individuals which are not regulated or monitored by government. Assessing and monitoring water quality in a fast growing urban and suburban settlement like the FCT therefore becomes imperative.

Assessing water quality generally involves comparing measured physico-chemical and biological concentrations with natural, background, or baseline concentrations and with guidelines established to protect human health or ecological communities. Some of the more commonly used physico-chemical indicators to describe and assess water quality include temperature, dissolved oxygen, pH, total dissolved solids (TDS), electrical conductivity and suspended sediments. Other indicators of water quality include nitrate, sulphate, coliforms as well as heavy metals.Groundwater quality in any locality is impacted by the chemical composition of the aquifer through which it migrates as well as land use in form of urbanisation and industrialisation.The pH is a measure of acidity or alkalinity of water. Water with very low or very high pH can cause acid/alkali burns and severe irritation of mucous membrane. High nitrate in water is indicative of agricultural land use pollution and can cause chronic fatigue and failure to thrive in human beings and cyanosis in babies. Electrical conductivity is an indicator of total dissolved solids and establishes if the water is drinkable and capable of slaking thirst. High TDS may make the water taste salty and may cause salt overload in sensitive groups. It can also increase dehydration. When faecal coliforms are found in any water source, it indicates that the water is polluted with human and animal excretion and consuming such water may lead to gastro-intestinal diseases. Heavy metals such as lead, arsenic, mercury, cadmium and copper, when present in water in high concentrations can be carcinogenic or have effects on kidney.Bioaccumulation of heavy metals above the threshold value may lead to toxicity. This could result from anthropogenic activities such as mining, chemical manufacturing and agriculture, and from hospital wastewater and electronic wastes (Krishna *et al.,* 2018). Urban aquifers such as we have in the FCT are often prone to pollution from industrial activities and urban development and this pollution may last hundreds of years because groundwater moves slowly. Therefore, hydrogeochemical investigation becomes important in assessing groundwater quality which may give a clear information about the subsurface geologic environment in which the water occurs and understanding the mechanisms controlling groundwater quality.

A number of studies have been carried out on the groundwater and surface water quality in Abuja in terms of the chemistry of the major ions and heavy metals (NWRI, 2016) and through multivariate statistical techniques (Dan-Hassan *et al*., 2016, Igibah and Tanko, 2019) for domestic and irrigation purposes. However, classification of hydrogeochemical facies in terms of rock types, mechanisms controlling groundwater quality and determination of hazard index and assessing health risk associated with ingesting heavy metals in the groundwater of the FCT, Abuja havenot been carried out. This study used the result of the national assessment of drinking water quality in FCT, Abuja carried out in 2016 by the National Water Resources Institute, Kaduna, under the programme "National Assessment of Drinking Water Quality Project" to characterise the groundwater resources in the six Area Councils of the FCT on the basis of rock types, determine the mechanisms controlling groundwater quality and determine the hazard index and possible health risk (if any) associated with ingesting heavy metals in the groundwater in the study area.

## 2.0 STUDY AREA

## 2.1 Location

Abuja, the Nigerian Federal Capital Territory was createdby Decree No.6 of 1976, following the resolution to move the nation's capital away from Lagos in the southern coastal area to a more central place insideNigeria, devoid ofdomination by any of the majorethnic groups. It is located north of the confluence of Niger River and Benue River and lies approximately between longitudes 6° 45'and 7° 37'E and latitudes 8° 21'N and 9° 18'N (Figure 1). The Federal Capital Territoryis made up of six area councils and has an approximate landmass of about 7,315 km$^2$. It is bordered by Niger State to the west, Kaduna State to the north, Nasarawa State to the east and Kogi State to the southwest. The population of the FCT, Abuja was 1,406,239 in 2006 (National Population Commission, 2011) and was projected at 6 million by 2016. About 43% of this population live in the metropolitan Abuja while the remaining population live in the satellite towns around the metropolitan area. The socio-economic activities of the population include agriculture and little mining. Natural resources in the area include marble, tin, clay, mica and tantalite.

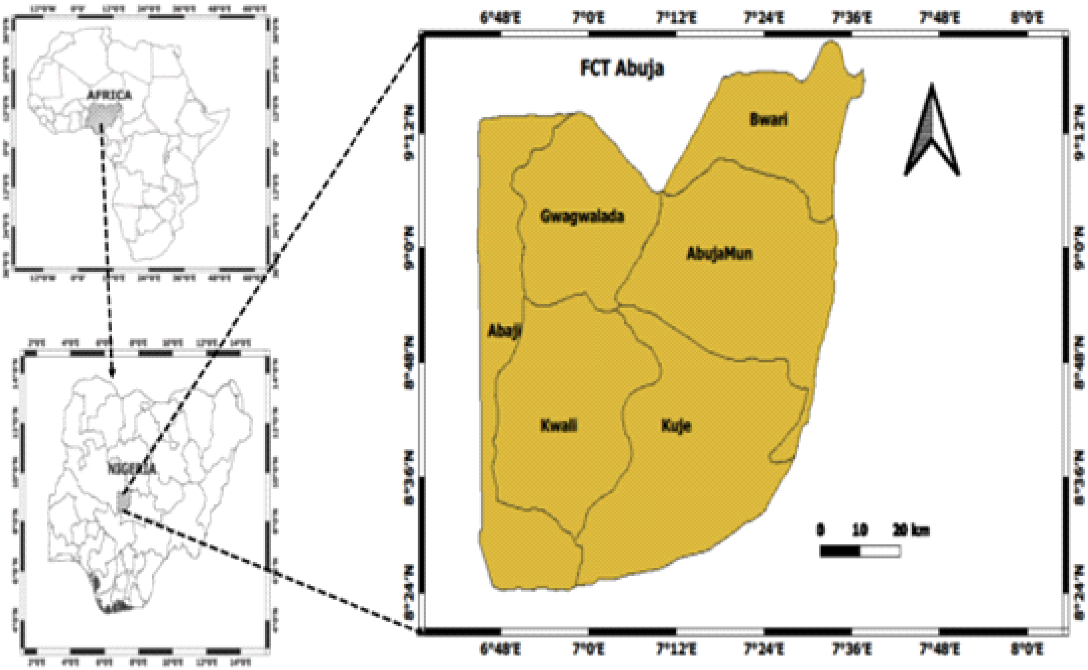



Figure 1: Location map of the FCT, Abuja

## 2.2 Geology, Climate and Vegetation

The geology of the FCT Abuja can be classified into 4 groups: (1) the migmatite-gneiss complex, consisting of mixture of granite-gneiss, migmatite, migmatite-gneiss and biotite-hornblende gneiss; (2) the granitoids, consisting of undifferentiated older granites, biotite-hornblende granite, biotite granite and the younger granite porphyry; (3) the metasediments, consisting of quartzite, quartzite-muscovite schist, muscovite schist, amphibolite schist and marble; and (4) the Cretaceous rocks of sedimentary origin from the Nupe Basin (Figure 2).

The granitoids are believed to be pre-, syn- and post tectonic rocks, with varied composition and indicate longer magmatic cycles related to the Pan African Orogeny (Rahaman, 1988; Mac Donald*et al.*, 2008).The older granites form large intrusive masses generally oblique in nature forming dissected zones of the

Zuma/Bwari-Aso hills and outcrops of the Gwagwa Plains, while the biotite-hornblende granite, and biotite granite form ridge rows trending northeast - southwest throughout the territory (Dan-Hassan *et al.*, 2016). Metasediments form an actuate structure that extends from the north-eastern part of the FCT, along eastern part to the southern part. The Nupe Basin forms a NW-SE trending embayment (Obaje, 2009) containing the almost flat-lying Cretaceous sediments of sandstone and claystone overlying the crystalline Precambrian rocks.

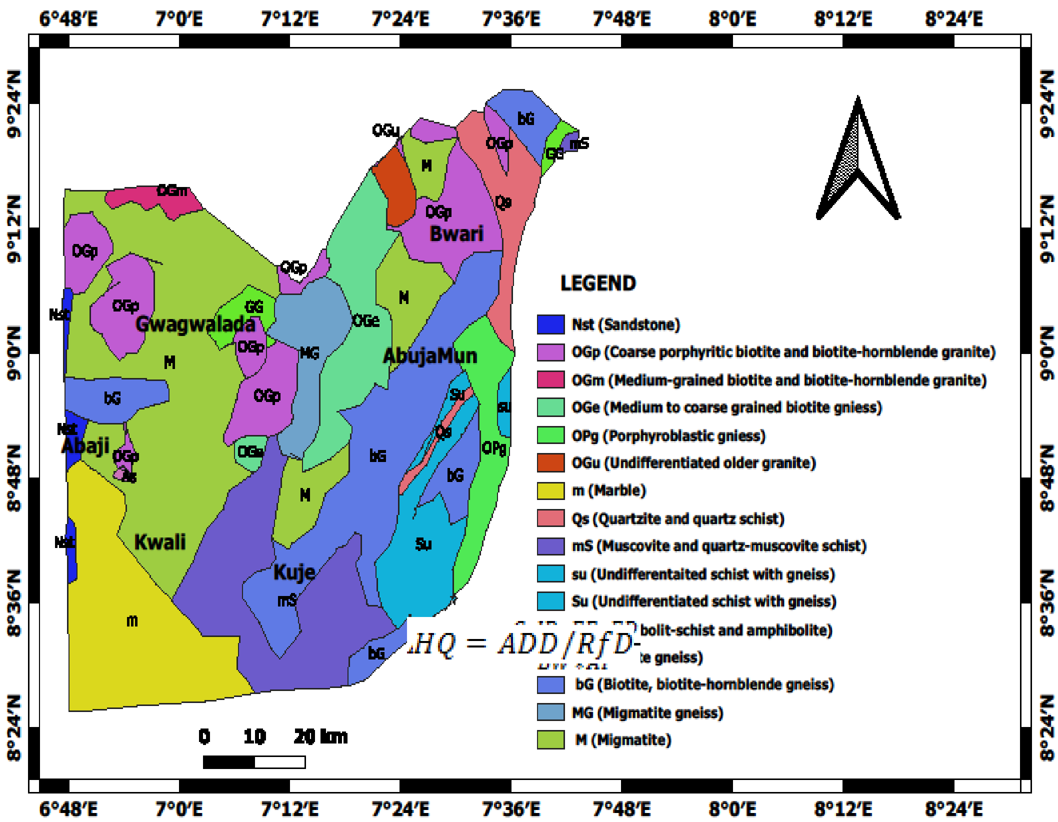



Figure 2: Geological map of FCT, Abuja (Modified after NGSA, 2006)

The FCT, Abuja is within the tropical savannah climate with sparse forests in its southern parts. There are two distinct seasons with a brief period of cold harmattan in between. The rainy season occurs between April and October with daily temperatures ranging between 22 °C at night and 28 °C during the day, followed by a dry season between November and March when the daily temperature can be high as 40 °C. There is a cool dry spell in the months of December and January when the dusty and dry harmattan winds of the north-easterly type sets in during which night time temperature can be as low as 12 °C.

## 3.0 METHODOLOGY

The result of the quality analysis of fifty (50) groundwater samples taken across the six area councils of the FCT, Abuja as contained in the report of the Assessment of Drinking Water Quality in Federal Capital Territory (FCT), 2016 produced by the National Water Resources Institute, Kaduna was reviewed and analysed for this study. The boundary map of FCT was digitized using QGIS 3.10 software and the geographical coordinates of the groundwater sampling points were placed on the boundary map which was then overlaid on the geological map of FCT all inQGIS 3.10environment to determine which rock type forms the aquifer for each sampling point. The identity of each point falling on a particular rock type was established and a plot of major ions (Ca, Mg, Na, K, Cl, $SO_4$ and $HCO_3$) from the results of water quality analysis for samples on the rock type was made on Piper trilinear diagram using GW_Chart software to characterise the geochemical evolution of water samples from that rock.

Gibbs diagram was plottedto establish the relationship between water composition and aquifer lithological characteristics. To plot the Gibbs diagram, the Gibbs ratios for major ions were calculated using the ratios (Gibbs, 1970):

Gibbs ratio I (for cation) =
Na + K / (Na + K + Ca) (1)
Gibbs ratio II (for anion) = Cl/ (Cl + $HCO_3$)(2)

These were plotted against the TDS values on the Gibbs diagram.

The health risks associated with ingestion of heavy metals in groundwater samples were assessed using the average daily dose (ADD) and hazard quotient (HQ) to determine hazard index (HI). The ADD for each heavy metal was calculated using the equation below (USEPA, 2005):

$$ADD = \frac{C * IR * EF * ED}{BW * AT} \quad (3)$$

Where
ADD= average daily dose (mg/kg/day)
C= average concentration of the heavy metal in groundwater (mg/L)
IR= ingestion rate (2L/day on average)
EF= exposure frequency (365days/year)
ED= exposure duration (70 years on average)
BW= body weight (70 kg for average adult)
AT= averaging time = EF*ED
The hazard quotient (HQ) for the potential non-carcinogenic risk for each heavy metal was calculated usingthe equation(USEPA, 2005):

$$HQ = ADD/RfD (4)$$

Where RfD= oral toxicity reference dose for each heavy metal as given by USEPA, 2012 in the table below:

| Heavy metal | RfD (mg/kg/day) |
|---|---|
| Cu | 0.0371 |
| Co | 0.02 |
| Fe | 0.7 |
| Pb | 0.0035 |
| Zn | 0.3 |
| Cr | 0.003 |
| Cd | 0.001 |
| Al | 0.0004 |
| As | 0.0003 |

*(Source: USEPA, 2012)*

The overall potential non-carcinogenic risk, expressed as hazard index (HI) posed by all heavy metals in a water sample was determined by summing up all the respective hazard quotient (HQ) values of each metal present in the water sample (USEPA, 2005). Thus:

$$HI = HQ_{Cr} + HQ_{Pb} + HQ_{Cd} + HQ_{As} \quad (5)$$

Where

HI= hazard index
$HQ_{Cr}$ = hazard quotient of chromium
$HQ_{Pb}$ = hazard quotient of lead
$HQ_{Cd}$ = hazard quotient of cadmium
$HQ_{As}$ = hazard quotient of arsenic

If the HI ? 1, there is no significant risk of non-carcinogenic effect anticipated, but if HI ? 1 there is a probability that non-carcinogenic risk effects may occur which tends to increase with increase in HI value (Kusin*et al*., 2018).

## 4.0 RESULTS AND DISCUSSION

### 4.1 Hydrogeochemistry of Physicochemical Parameters

The chemical characteristics of the groundwater in the FCT was examined on the basis of lithological units in which the boreholes were drilled. On the basis of aquifer lithological units twenty four (24) samples were taken from the migmatite-gneiss complex, nineteen (19) from the granitoids, six (6) from marble and one (1) from sandstone. Figure 3 shows the distribution of the sample locations across the various rock types present in the study area.

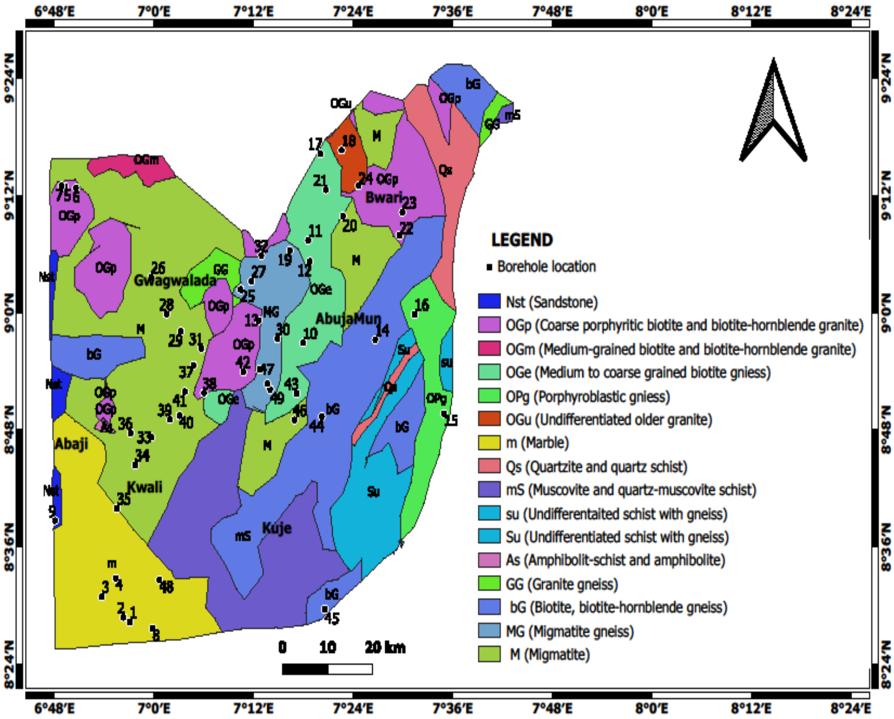



Figure 3: Location of boreholes on different rock types in FCT, Abuja

The major water quality parameters examined varied across the different rock types. Figure 4 shows the distribution of the mean values of the examined parameters across the different rock types present.

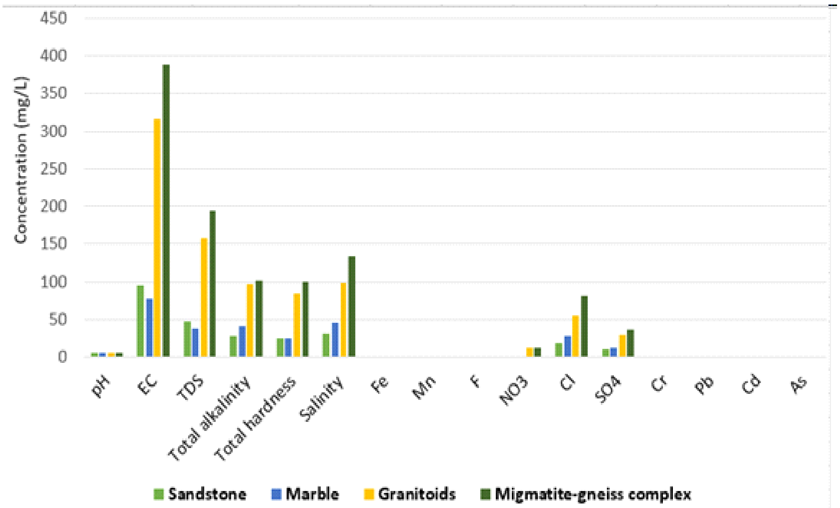



Figure 4: Mean values of analysed parameters across the different rock types.

Table 2 below shows the recorded physical parameters in relation to aquifer lithology. Table 3 shows the recorded chemical (non-toxic) parameters while table 4 shows the recorded chemical (toxic) parameters and the calculated hazard index (HI) posed by these toxic parameters.

**Table 2: Physical parameters in groundwater samples in FCT in relation to aquifer lithology**

| S/N | Location | Long (E) | Lat (N) | pH | EC (µS/cm) | TDS (mg/L) | Turb. (NTU) |
|---|---|---|---|---|---|---|---|
| 1 | S/Gari Abaji | 6.95145 | 8.47241 | 4.4 | 27.4 | 13.1 | 0.2 |
| 2 | Agyana Abaji | 6.93897 | 8.48022 | 5.6 | 30.1 | 14.5 | 0.13 |
| 3 | U/Gwari Abaji | 6.89547 | 8.51583 | 5.8 | 15.44 | 7.79 | 0.4 |
| 4 | PPMC, Awawa | 6.92324 | 8.54692 | 7.4 | 156.3 | 78.5 | 2.44 |
| 5 | Gidan Sarki, Fuka | 6.82129 | 9.21512 | 6.8 | 299 | 154 | 1.79 |
| 6 | Bashiya, Old Gawu | 6.84374 | 9.21231 | 6.6 | 286 | 145 | 0.08 |
| 7 | Jamigbe | 6.81487 | 9.21562 | 7.4 | 374 | 186 | 1.05 |
| 8 | U/Liman, Atako | 6.99729 | 8.46157 | 5.7 | 14.49 | 8.43 | 0.26 |
| 9 | U/Hausawa, Yaba | 6.80093 | 8.64522 | 5.3 | 95.3 | 47.4 | 9.11 |
| 10 | Gosa Sarki, Gosa | 7.29978 | 8.94824 | 6.9 | 299 | 149 | 1.71 |
| 11 | Guida | 7.30968 | 9.12346 | 6 | 252 | 125 | 0.05 |
| 12 | Gwagwa | 7.31293 | 9.08697 | 6.3 | 1244 | 622 | 0.43 |
| 13 | Iddo Sarki | 7.21001 | 8.98615 | 6.7 | 649 | 323 | 0.15 |
| 14 | U/Bako, Kabusa | 7.44444 | 8.95364 | 6.6 | 35.74 | 17.9 | 0.07 |
| 15 | U/Hausawa, Karshi | 7.58262 | 8.82769 | 5.7 | 266 | 133 | 0.09 |
| 16 | LEA Pri. Sch. Kobi | 7.52395 | 8.99687 | 5.6 | 61.4 | 30.9 | 0.3 |
| 17 | Rehab. Centre, Bwari | 7.33397 | 9.27063 | 5.9 | 177.4 | 87.5 | 3.03 |
| 18 | Bwari Med. Cent. Bwari | 7.37688 | 9.27662 | 6.5 | 74.3 | 37 | 0.75 |
| 19 | Dei-Dei | 7.27274 | 9.10537 | 5.4 | 854 | 438 | 0.72 |
| 20 | Dutsen Makaranta | 7.37932 | 9.16387 | 5.7 | 440 | 219 | 0.47 |
| 21 | Kuchibuyi | 7.34523 | 9.20895 | 6.5 | 182.1 | 92.9 | 0.03 |
| 22 | Eneji, Mpape | 7.493 | 9.13151 | 6.2 | 85.9 | 43 | 0.06 |
| 23 | Durumi | 7.49889 | 9.17088 | 7.1 | 87.2 | 43.9 | 4.43 |
| 24 | Ushafa | 7.41133 | 9.21618 | 6.4 | 352 | 175 | 0.9 |
| 25 | Anagada | 7.17413 | 9.03923 | 6.9 | 528 | 264 | 0.08 |
| 26 | Dobi | 6.99438 | 9.06022 | 7.4 | 397 | 198 | 0.72 |
| 27 | Tunga Maje | 7.19595 | 9.05295 | 6.7 | 185.1 | 92.4 | 0.98 |
| 28 | Paikon-Kore | 7.02517 | 8.99761 | 6.9 | 287 | 144 | 0.71 |
| 29 | Passo | 7.05393 | 8.96788 | 7.1 | 287 | 142 | 2.25 |
| 30 | Sauka-Airport | 7.24818 | 8.95476 | 6.6 | 149.9 | 75 | 4.1 |
| 31 | 13-13 Road, U/Dodo | 7.09548 | 8.93866 | 7 | 278 | 139 | 0.36 |
| 32 | LEA Pri. Sch. Zuba | 7.2157 | 9.09746 | 7.2 | 883 | 439 | 0.72 |
| 33 | Pri.Sch. Alheri Village | 6.99454 | 8.78723 | 5 | 139.3 | 69.9 | 190 |
| 34 | Piri | 6.96212 | 8.74015 | 6.1 | 1530 | 760 | 1.88 |
| 35 | U/Hausawa, Kwaita | 6.92553 | 8.666475 | 6 | 241 | 123 | 0.39 |
| 36 | U/Madaki, Dafa | 6.95304 | 8.7946 | 6.4 | 280 | 137 | 0.65 |
| 37 | Mama Faruk Str. Bako | 7.07911 | 8.91004 | 7.7 | 308 | 161 | 8.4 |
| 38 | Kilankwa 1 | 7.10071 | 8.86303 | 7.3 | 361 | 173 | 0.42 |
| 39 | Pri. Health Care, Kwali | 7.03221 | 8.81761 | 6.5 | 248 | 128 | 0.12 |
| 40 | LEA Pri.Sch. Lambata | 7.05104 | 8.824 | 6.8 | 361 | 172 | 0.24 |
| 41 | Sheda 1 | 7.06208 | 8.86517 | 6.9 | 296 | 155 | 0.58 |
| 42 | Chibiri | 7.17925 | 8.8986 | 6.5 | 937 | 453 | 2.74 |
| 43 | Dafara | 7.28658 | 8.86167 | 6.5 | 144.3 | 71.9 | 0.47 |
| 44 | Gaube | 7.3375 | 8.82214 | 6.2 | 108 | 54.9 | 1.28 |
| 45 | GSS TudunKarya | 7.3435 | 8.49405 | 6.1 | 74 | 36.8 | 4.93 |
| 46 | LEA Pri. Sch. Pegi | 7.28225 | 8.8171 | 7.2 | 164.9 | 83.7 | 0.54 |
| 47 | Shetuko | 7.2125 | 8.90295 | 6.4 | 592 | 300 | 0.24 |
| 48 | Tika (Rubochi) | 7.01094 | 8.54424 | 5.4 | 228 | 109 | 0.32 |
| 49 | Union Home Area | 7.23327 | 8.86903 | 7.6 | 184.4 | 91.7 | 0.28 |
| 50 | U/Boyi, U/Gede | 7.22783 | 8.87852 | 6.3 | 338 | 164 | 3.3 |

Sandstone   Marble   Granitoids   Migmatite-gneiss complex

**Table 3: Chemical (non-toxic) parameters in Groundwater Samples in FCT in relation to aquifer lithology**

| S/N | Location | Long (E) | Lat (N) | Total Alkal | Total Hard | Salinity | Fe (mg/L) | Mn (mg/L) | $F^-$ (mg/L) | $NO_3^-$ (mg/L) | $Cl^-$ (mg/L) | $SO_4^{2-}$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | S/Gari Abaji | 6.95145 | 8.47241 | 28 | 12 | 53.6 | 0.2 | 0.14 | 0.21 | 1.23 | 33 | 8 |
| 2 | Agyana Abaji | 6.93897 | 8.48022 | 23 | 18 | 28.9 | 0.05 | 0.08 | 0.13 | 0.04 | 18 | 10 |
| 3 | U/Gwari Abaji | 6.89547 | 8.51583 | 27 | 10 | 48.7 | 0.1 | 0.11 | 0.04 | 0.48 | 30 | 4 |
| 4 | PPMC, Awawa | 6.92324 | 8.54692 | 94 | 28 | 42.1 | 0.01 | 0.05 | 0 | 0.62 | 26 | 12 |
| 5 | Gidan Sarki, Fuka | 6.82129 | 9.21512 | 104 | 54 | 55.1 | 0.05 | 0.06 | 1.15 | 0.08 | 35 | 25 |
| 6 | Bashiya, Old Gawu | 6.84374 | 9.21231 | 103 | 25 | 53.6 | 0.15 | 0.14 | 1.2 | 3.92 | 33 | 11 |
| 7 | Jamigbe | 6.81487 | 9.21562 | 178 | 95 | 55.3 | 0 | 0.01 | 0.46 | 1.05 | 34 | 35 |
| 8 | U/Liman, Atako | 6.99729 | 8.46157 | 21 | 16 | 23.9 | 0.1 | 0.09 | 0.01 | 0.03 | 14.5 | 9 |
| 9 | U/Hausawa, Yaba | 6.80093 | 8.64522 | 28 | 25 | 31.1 | 0.1 | 0.08 | 0.25 | 1.4 | 19 | 10 |
| 10 | Gosa Sarki, Gosa | 7.29978 | 8.94824 | 121 | 89 | 55.1 | 0.45 | 0.8 | 0.49 | 19 | 35 | 33 |
| 11 | Guida | 7.30968 | 9.12346 | 111 | 96 | 51.2 | 0.01 | 0.03 | 0.34 | 13.6 | 31 | 36 |
| 12 | Gwagwa | 7.31293 | 9.08697 | 242 | 402 | 359.6 | 0.06 | 0.09 | 0.87 | 26 | 217 | 98 |
| 13 | Iddo Sarki | 7.21001 | 8.98615 | 178 | 100 | 151.8 | 0 | 0.01 | 1.48 | 1.7 | 92 | 42 |
| 14 | U/Bako, Kabusa | 7.44444 | 8.95364 | 29 | 22 | 47 | 0.01 | 0.08 | 0.75 | 2.7 | 28 | 10 |
| 15 | U/Hausawa, Karshi | 7.58262 | 8.82769 | 40 | 49 | 78.4 | 0 | 0.03 | 0.18 | 3.9 | 47 | 22 |
| 16 | LEA Pri. Sch. Kobi | 7.52395 | 8.99687 | 34 | 15 | 64.3 | 0.2 | 0.16 | 0.24 | 0.18 | 39 | 9 |
| 17 | Rehab. Centre, Bwari | 7.33397 | 9.27063 | 117 | 55 | 66 | 0.08 | 0.01 | 0.69 | 1.18 | 40 | 26 |
| 18 | Bwari Med. Cent. Bwari | 7.37688 | 9.27662 | 32 | 11 | 52 | 0.06 | 0.07 | 0.36 | 28 | 31 | 7 |
| 19 | Dei-Dei | 7.27274 | 9.10537 | 117 | 262 | 294 | 0.02 | 0.06 | 0.57 | 0.52 | 178 | 67 |
| 20 | Dutsen Makaranta | 7.37932 | 9.16387 | 46 | 109 | 236 | 0.07 | 0.06 | 0.15 | 24 | 143 | 45 |
| 21 | Kuchibuyi | 7.34523 | 9.20895 | 96 | 48 | 94.1 | 0.16 | 0.12 | 0.38 | 13.8 | 57 | 23 |
| 22 | Eneji, Mpape | 7.493 | 9.13151 | 35 | 18 | 70.9 | 0 | 0 | 0 | 0.44 | 43 | 11 |
| 23 | Durumi | 7.49889 | 9.17088 | 33 | 19 | 29.7 | 0.06 | 0.05 | 0.29 | 11 | 18 | 13 |
| 24 | Ushafa | 7.41133 | 9.21618 | 109 | 97 | 163 | 0.07 | 0.08 | 0.55 | 28 | 98 | 35 |
| 25 | Anagada | 7.17413 | 9.03923 | 151 | 136 | 200 | 0.01 | 0.02 | 1.18 | 13.6 | 121 | 54 |
| 26 | Dobi | 6.99438 | 9.06022 | 67 | 135 | 168.3 | 0 | 0.04 | 0.94 | 19.6 | 102 | 50 |
| 27 | Tunga Maje | 7.19595 | 9.05295 | 88 | 46 | 92.4 | 0 | 0.08 | 0.52 | 1.96 | 56 | 21 |
| 28 | Paikon-Kore | 7.02517 | 8.99761 | 175 | 45 | 52.8 | 0.08 | 0.04 | 1.08 | 3.1 | 32 | 20 |
| 29 | Passo | 7.05393 | 8.96788 | 72 | 98 | 41.3 | 0 | 0.02 | 1.07 | 0.96 | 25 | 34 |
| 30 | Sauka-Airport | 7.24818 | 8.95476 | 65 | 149 | 89.1 | 0.03 | 0.01 | 0.38 | 11.4 | 53 | 59 |
| 31 | 13-13 Road, U/Dodo | 7.09548 | 8.93866 | 142 | 94 | 94.1 | 0.01 | 0.05 | 0.97 | 12 | 57 | 30 |
| 32 | LEA Pri. Sch. Zuba | 7.2157 | 9.09746 | 80 | 247 | 330 | 0.45 | 0.67 | 0.95 | 23 | 200 | 75 |
| 33 | Pri.Sch. Alheri Village | 6.99454 | 8.78723 | 42 | 29 | 48 | 1.5 | 1.1 | 0.25 | 10.43 | 29 | 14 |
| 34 | Piri | 6.96212 | 8.74015 | 260 | 305 | 266.8 | 0.2 | 0.06 | 0.97 | 36.3 | 161 | 84 |
| 35 | U/Hausawa, Kwaita | 6.92553 | 8.666475 | 20 | 51 | 101.4 | 0.05 | 0.07 | 0.16 | 23.76 | 61.5 | 28 |
| 36 | U/Madaki, Dafa | 6.95304 | 8.7946 | 130 | 100 | 66.8 | 0.05 | 0.03 | 0.4 | 9.42 | 40.5 | 36 |
| 37 | Mama Faruk Str. Bako | 7.07911 | 8.91004 | 125 | 93 | 174.8 | 0.35 | 0.29 | 0.05 | 4.33 | 105 | 32 |
| 38 | Kilankwa 1 | 7.10071 | 8.86303 | 87 | 87 | 106.4 | 0.35 | 0.28 | 0.46 | 13.11 | 64.5 | 30 |
| 39 | Pri. Health Care, Kwali | 7.03221 | 8.81761 | 91 | 62 | 89.1 | 0.15 | 0.17 | 0.71 | 8.58 | 53.9 | 29 |
| 40 | LEA Pri.Sch. Lambata | 7.05104 | 8.824 | 138 | 87 | 116.3 | 0.2 | 0.1 | 1.43 | 8.4 | 70.5 | 32 |
| 41 | Sheda 1 | 7.06208 | 8.86517 | 140 | 88 | 117.1 | 0.25 | 0.26 | 0.81 | 5.9 | 71 | 31 |
| 42 | Chibiri | 7.17925 | 8.8986 | 181 | 274 | 200.4 | 0.35 | 0.24 | 0.47 | 42.9 | 121.5 | 79 |
| 43 | Dafara | 7.28658 | 8.86167 | 32 | 43 | 65.2 | 0.05 | 0.04 | 0.13 | 15.44 | 39.5 | 21 |
| 44 | Gaube | 7.3375 | 8.82214 | 29 | 29 | 37.9 | 0.05 | 0.09 | 0.08 | 13.86 | 23 | 15 |
| 45 | GSS TudunKarya | 7.3435 | 8.49405 | 34 | 27 | 34.7 | 0.05 | 0.07 | 0.4 | 1.28 | 21 | 13 |
| 46 | LEA Pri. Sch. Pegi | 7.28225 | 8.8171 | 87 | 60 | 75.9 | 0.05 | 0.08 | 0.19 | 5.9 | 46 | 25 |
| 47 | Shetuko | 7.2125 | 8.90295 | 128 | 43 | 137.7 | 0.35 | 0.25 | 1.08 | 36.52 | 83.5 | 20 |
| 48 | Tika (Rubochi) | 7.01094 | 8.54424 | 51 | 67 | 82.5 | 0.05 | 0.06 | 0.01 | 0.07 | 49 | 31 |
| 49 | Union Home Area | 7.23327 | 8.86903 | 43 | 79 | 85.8 | 0.15 | 0.1 | 0.15 | 11.31 | 52 | 34 |
| 50 | U/Boyi, U/Gede | 7.22783 | 8.87852 | 165 | 11 | 178.2 | 0.05 | 0.06 | 0.07 | 9.72 | 108 | 38 |

Sandstone   Marble   Granitoids   Migmatite-gneiss complex

**Table 4: Chemical (toxic) parameters and calculated hazard index (HI) in groundwater samples in FCT**

| S/N | Location | Long (E) | Lat (N) | Cr (mg/L) | Pb (mg/L) | Cd (mg/L) | As (mg/L) | Hazard |
|---|---|---|---|---|---|---|---|---|
| 1 | S/Gari Abaji | 6.95145 | 8.47241 | 0 | 0.001 | 0.0011 | 0 | 0.04 |
| 2 | Agyana Abaji | 6.93897 | 8.48022 | 0.01 | 0.0022 | 0.0001 | 0 | 0.12 |
| 3 | U/Gwari Abaji | 6.89547 | 8.51583 | 0.03 | 0.0044 | 0.0003 | 0 | 0.33 |
| 4 | PPMC, Awawa | 6.92324 | 8.54692 | 0.04 | 0.0089 | 0 | 0 | 0.45 |
| 5 | Gidan Sarki, Fuka | 6.82129 | 9.21512 | 0.03 | 0.0011 | 0.0012 | 0 | 0.33 |
| 6 | Bashiya, Old Gawu | 6.84374 | 9.21231 | 0.02 | 0.0068 | 0.0004 | 0 | 0.26 |
| 7 | Jamigbe | 6.81487 | 9.21562 | 0 | 0.0036 | 0.0013 | 0 | 0.07 |
| 8 | U/Liman, Atako | 6.99729 | 8.46157 | 0.02 | 0.0091 | 0 | 0 | 0.26 |
| 9 | U/Hausawa, Yaba | 6.80093 | 8.64522 | 0.03 | 0.0058 | 0.0006 | 0 | 0.35 |
| 10 | Gosa Sarki, Gosa | 7.29978 | 8.94824 | 0.04 | 0.0013 | 0.0009 | 0 | 0.42 |
| 11 | Guida | 7.30968 | 9.12346 | 0.04 | 0.0011 | 0.0021 | 0 | 0.45 |
| 12 | Gwagwa | 7.31293 | 9.08697 | 0.03 | 0.0013 | 0.0009 | 0 | 0.32 |
| 13 | Iddo Sarki | 7.21001 | 8.98615 | 0 | 0.0014 | 0.0007 | 0 | 0.03 |
| 14 | U/Bako, Kabusa | 7.44444 | 8.95364 | 0.04 | 0.0067 | 0.0006 | 0 | 0.45 |
| 15 | U/Hausawa, Karshi | 7.58262 | 8.82769 | 0.02 | 0.0069 | 0.0013 | 0 | 0.28 |
| 16 | LEA Pri. Sch. Kobi | 7.52395 | 8.99687 | 0.03 | 0.0057 | 0.0019 | 0 | 0.39 |
| 17 | Rehab. Centre, Bwari | 7.33397 | 9.27063 | 0.01 | 0.007 | 0.0013 | 0 | 0.19 |
| 18 | Bwari Med. Cent. Bwari | 7.37688 | 9.27662 | 0.04 | 0.0012 | 0.0008 | 0 | 0.41 |
| 19 | Dei-Dei | 7.27274 | 9.10537 | 0.03 | 0.0036 | 0.0017 | 0 | 0.36 |
| 20 | Dutsen Makaranta | 7.37932 | 9.16387 | 0.01 | 0 | 0.0017 | 0 | 0.14 |
| 21 | Kuchibuyi | 7.34523 | 9.20895 | 0.04 | 0.002 | 0.0009 | 0 | 0.42 |
| 22 | Eneji, Mpape | 7.493 | 9.13151 | 0.05 | 0.0071 | 0.002 | 0 | 0.59 |
| 23 | Durumi | 7.49889 | 9.17088 | 0.02 | 0.0063 | 0.0012 | 0 | 0.28 |
| 24 | Ushafa | 7.41133 | 9.21618 | 0.05 | 0.0068 | 0.0012 | 0 | 0.57 |
| 25 | Anagada | 7.17413 | 9.03923 | 0.02 | 0.001 | 0.0009 | 0 | 0.22 |
| 26 | Dobi | 6.99438 | 9.06022 | 0.01 | 0 | 0.0012 | 0 | 0.13 |
| 27 | Tunga Maje | 7.19595 | 9.05295 | 0.02 | 0.0079 | 0.0014 | 0 | 0.29 |
| 28 | Paikon-Kore | 7.02517 | 8.99761 | 0.03 | 0.0045 | 0.0011 | 0 | 0.35 |
| 29 | Passo | 7.05393 | 8.96788 | 0.04 | 0.0046 | 0.0025 | 0 | 0.49 |
| 30 | Sauka-Airport | 7.24818 | 8.95476 | 0.01 | 0.0013 | 0.0012 | 0 | 0.14 |
| 31 | 13-13 Road, U/Dodo | 7.09548 | 8.93866 | 0.03 | 0.0032 | 0.0014 | 0 | 0.35 |
| 32 | LEA Pri. Sch. Zuba | 7.2157 | 9.09746 | 0.05 | 0.0023 | 0.0008 | 0 | 0.52 |
| 33 | Pri.Sch. Alheri Village | 6.99454 | 8.78723 | 0.04 | 0.003 | 0.0022 | 0 | 0.47 |
| 34 | Piri | 6.96212 | 8.74015 | 0.03 | 0.0011 | 0.0017 | 0 | 0.34 |
| 35 | U/Hausawa, Kwaita | 6.92553 | 8.666475 | 0.01 | 0.004 | 0.0011 | 0 | 0.16 |
| 36 | U/Madaki, Dafa | 6.95304 | 8.7946 | 0.04 | 0.0069 | 0.0017 | 0 | 0.49 |
| 37 | Mama Faruk Str. Bako | 7.07911 | 8.91004 | 0.01 | 0.0086 | 0.0024 | 0 | 0.23 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 38 | Kilankwa 1 | 7.10071 | 8.86303 | 0.02 | 0 | 0.0018 | 0 | 0.24 |
| 39 | Pri. Health Care, Kwali | 7.03221 | 8.81761 | 0.03 | 0.0012 | 0.001 | 0 | 0.32 |
| 40 | LEA Pri.Sch. Lambata | 7.05104 | 8.824 | 0.02 | 0.0097 | 0.0013 | 0 | 0.31 |
| 41 | Sheda 1 | 7.06208 | 8.86517 | 0.04 | 0.0096 | 0.0018 | 0 | 0.51 |
| 42 | Chibiri | 7.17925 | 8.8986 | 0.02 | 0 | 0.0017 | 0 | 0.24 |
| 43 | Dafara | 7.28658 | 8.86167 | 0.05 | 0.0051 | 0.0012 | 0 | 0.55 |
| 44 | Gaube | 7.3375 | 8.82214 | 0.01 | 0.0004 | 0.0016 | 0 | 0.14 |
| 45 | GSS TudunKarya | 7.3435 | 8.49405 | 0.04 | 0 | 0.0022 | 0 | 0.44 |
| 46 | LEA Pri. Sch. Pegi | 7.28225 | 8.8171 | 0.03 | 0.0099 | 0.0014 | 0 | 0.41 |
| 47 | Shetuko | 7.2125 | 8.90295 | 0.02 | 0 | 0.0016 | 0 | 0.24 |
| 48 | Tika (Rubochi) | 7.01094 | 8.54424 | 0.03 | 0.0027 | 0.002 | 0 | 0.36 |
| 49 | Union Home Area | 7.23327 | 8.86903 | 0.01 | 0.0033 | 0.0019 | 0 | 0.18 |
| 50 | U/Boyi, U/Gede | 7.22783 | 8.87852 | 0.02 | 0 | 0.002 | 0 | 0.25 |

### 4.1.1 pH

The pH of water on migmatite-gneiss complex varies between 5.0 and 7.7 with an average value of 6.5. On granitoids, the pH varies between 5.9 and 7.4 with an average value of 5.5. The pH on marble varies between 4.4 and 7.4 with an average value of 5.7, while on the sandstone the pH value was 5.3. The pH value is lowest in marble and highest in migmatite-gneiss complex. About 58% of the water samples have pH values within the 6.5-8.5 Nigerian Standard for Drinking Water Quality, (NSDWQ, 2015) and World Health Organisation (WHO, 2017) recommended guideline values for drinking water. The pH has a marked effect on the taste of the water as well as on corrosion problems and mobilisation of heavy metals. Factors that influence pH can be natural or man-made. Natural causes occur due to interactions with surrounding rocks (particularly carbonate rocks) and other materials. The pH also fluctuates with precipitation (especially acid rain) and wastewater or mining discharges. $CO_2$ concentrations can also influence pH levels.

### 4.1.2 Electrical conductivity (EC) and Total Dissolved Solids (TDS)

Electrical conductivity is a measure of the ability of water to conduct electric current and it is an indicator of total dissolved solids in groundwater. The highest EC and TDS values of 1530 µS/cm and 760 mg/L respectively occur on migmatite-gneiss complex while the lowest values of 14.49 µS/cm and 7.79 mg/L occur on marble. Ninety six percent of the water samples have TDS values below the 500 mg/L (NSDWQ and WHO recommended values for drinking water).

### 4.1.3 Total Alkalinity

Total alkalinity is the acid neutralizing capacity of water. Alkalinity is determined by the soil and bedrock through which water passes. It is equal to the concentrations of $HCO_3$ and $CO_3$. Natural sources of alkalinity in water are rocks which contain carbonate, bicarbonate, and hydroxide compounds. Alkalinity has effect on the buffering capacity of water, i.e. the ability of water (or compound) to resist a change in pH. Thus, a high alkalinity means it will be difficult to change the pH of the water, or more importantly, greater ability of the water to change the pH of something else to which the water is added, e.g. soils or potted plants. Total alkalinity on migmatite ranges between 260 mg/L and 20 mg/L with an average value of

102.2 mg/l. On the granitoids, the values range between 242 mg/Land 29 mg/L with an average value of 97.4 mg/L.On marble, the values range between 94 mg/L and 21 mg/L with an average value of 40.7 mg/L. The value on sandstone is 28 mg/L. All the water samples have values below the NSDWQ and WHO recommended value of 500 mg/L for total alkalinity.

#### 4.1.4 Total Hardness

Hardness is the sum of ions which can precipitate as “hard particles” from water. It is comprised of the sum of calcium and magnesium. Hardness of water is an indication of how easy or difficult it is for soap to form lather. Water containing high concentrations of soluble calcium and magnesium is termed hard water. Total hardness value of water samples from migmatite-gneiss complex ranges between 305 mg/L and 11 mg/L with an average value of 99.7 mg/L. On granitoids, the value ranges between 402 mg/L and 11 mg/L with an average value of 83.7 mg/L. On marble the value ranges between 67 mg/L and 10 mg/L with an average value of 25.2 mg/L. The value of sandstone is 25 mg/L. 150 mg/L is the recommended value by NSDWQ for total hardness in water, and 5 samples, 3 on migmatite-gneiss complex and 2 on granitoids have values above the recommended value.

#### 4.1.5 Salinity

Salinity is a measure of the content of salts in water. Primary salinity in groundwater is due to weathering of rocks. Salinity values range between 294 mg/L and 41.3 mg/L on migmatite-gneiss complex; 359.6 mg/L and 34.7 mg/L on granitoids; 82.5 mg/L and 23.9 mg/L on marble; and the value of 31.1 mg/L on sandstone. The NSDWQ value of salinity is 200 mg/L and 12% of the samples have values above this recommended value.

#### 4.1.6 Iron (Fe) and Manganese (Mn)

The most common sources of iron and manganese in groundwater are from the weathering of iron and manganese bearing minerals. Industrial effluent, acid-mine drainage, sewage and landfill leachate may also locally contribute iron and manganese to groundwater. Reducing conditions, residence time, well depth, and salinity are the key factors leading to the dissolution and migration of iron and manganese in groundwater. Iron and manganese affect the taste of the water and may cause a reddish brown or black discolouration of fixtures and stains in laundry. It can cause growth of slimes of iron reducing bacteria that appears as black flecks in water. Of the water samples under discussion, iron and manganese have their highest values of 1.5 mg/L and 1.1 mg/L respectively in water samples from migmatite-gneiss complex and lowest value of 0.0 mg/L and in water samples from the granitoids and marble. Fourteen percent of the all water samples have iron values above the 0.3 mg/L stipulated value according to the NSDWQ standard and 16% have manganese values above the 0.2 mg/L of the NSDWQ standard.

#### 4.1.7 Fluoride (F)

Measured fluoride concentrations vary between 0.0 mg/L and 1.48 mg/L. The highest value occurs on the granitoids while the lowest values occur on marble and migmatite-gneiss complex. Natural sources of fluoride in groundwater include the weathering of fluoride bearing minerals like apatite, fluorite, biotite and hornblende. Anthropogenic sources of fluoride include the use of phosphate fertilisers and burning of coal during which aerial emission of fluoride in gaseous form reaches the ground by fall out of particulate fluorides and during rainfall they percolate with the rainwater thus reaching the groundwater. All the water samples have fluoride concentrations below the 1.5 mg/L recommended by NSDWQ.

#### 4.1.8 Nitrate($NO_3$)

The highest values of nitrate concentrations occur on the granitoids and migmatite-gneiss complex at 42.9 mg/L and 36.3 mg/L respectively, while the lowest values occur on the sandstone and marble at 1.4 mg/L and 1.23 mg/L.The average nitrate value on migmatite-gneiss complex is 11.87 mg/L, 12.48 mg/L on the granitoids, 0.41 mg/L on marble and 1.4 mg/L on sandstone. Natural concentrations of nitrate in groundwater does not exceed 10 mg/L, so values above 10 mg/L are indicative of anthropogenic pollution from poor sanitary conditions, indiscriminate use of higher fertilisers. All the water samples studied had 100% compliance with NSDWQ standard value of 45 mg/L in drinking water.

#### 4.1.9 Chloride (Cl)

Chloride concentration ranges between 217 mg/L and 18 mg/L in the water samples from the granitoids with an average value of 55.9 mg/L. It ranges between 200 mg/L and 25 mg/L in water samples from migmatite-gneiss complex with an average value of 80.6 mg/L, ranges between 49 mg/L and 14.5 mg/L with an average value of 28.4 mg/L on marble and 19 mg/L on sandstone. Chloride is one of the important inorganic anions present in groundwater. High chloride concentrations in water make it taste more salty and cause increased corrosion of metals.

#### 5.1.10 Sulphate ($SO_4$)

Water samples from migmatite-gneiss complex have sulphate ($SO_4$) concentrations between 98 mg/L and 7.0 mg/L with an average value of 29.6 mg/L, and on the granitoids the concentrations range between 84 mg/L and 9.0 mg/L with an average values of 37.0 mg/L. Those samples from marble have $SO_4$ values ranging between 31 mg/L and 4 mg/L with an average value of 12.3 mg/L and on sandstone the value is 10 mg/L. All the water samples have $SO_4$ concentrations below the 400 mg/L maximum allowable limit by WHO and NSDWQ.

#### 5.1.11 Heavy Metals

The four heavy metals analysed in this study were chromium (Cr), lead (Pb), cadmium (Cd) and arsenic (As). The concentrations of chromium on migmatite-gneiss complex and the granitoids range between 0.00 mg/L and 0.05 mg/L with average value at 0.03 mg/L. The water samples from marble aquifer have Cr concentrations between 0.00 mg/L and 0.04 mg/L with average value of 0.02 mg/L, while on the sandstone the value is 0.03 mg/L. Lead concentration is highest in the water samples from marble at 0.0091 mg/L, followed by migmatite-gneiss complex and granitoids at 0.0079 mg/L and 0.0071 mg/L, with average values of 0.0041 mg/L and 0.0031 mg/L respectively. The value from sandstone aquifer is 0.0058 mg/L. Cadmium concentration is highest in water samples from the granitoids at 0.12 mg/L, followed by migmatite-gneiss at 0.0024 mg/L and marble at 0.002 mg/L. In sandstone the value is 0.0006 mg/L. The lowest values of cadmium concentrations range between 0.0 mg/L and 0.0004 mg/L. All the water samples from all the rock types have zero value of arsenic. All the heavy metals have concentrations in the groundwater samples analysed below the WHO recommended guideline values and the NSDWQ standard of 0.05 mg/L for chromium, 0.01 mg/L for lead, 0.003 mg/ L for cadmium and 0.01 mg/L for arsenic.

### 4.2 Hydrogeochemical Facies

The hydrogeochemical characterization of water samples obtained from each rocktype was determined by plotting the relevant parameters on the Piper trilinear diagram. Piper trilinear diagrams plotted for water samples on each rock type are presented below in figure 5 (a-d)

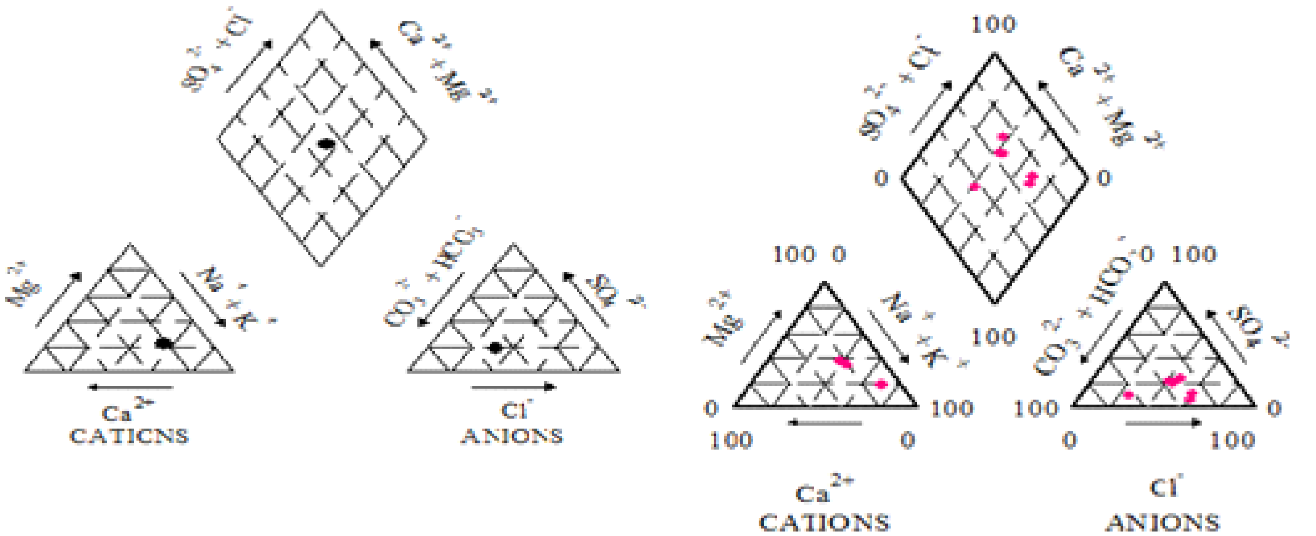



Figure 5: (a) Piper trilinear diagram for sample on sandstone, (b) Piper trilinear diagram for samples on marble

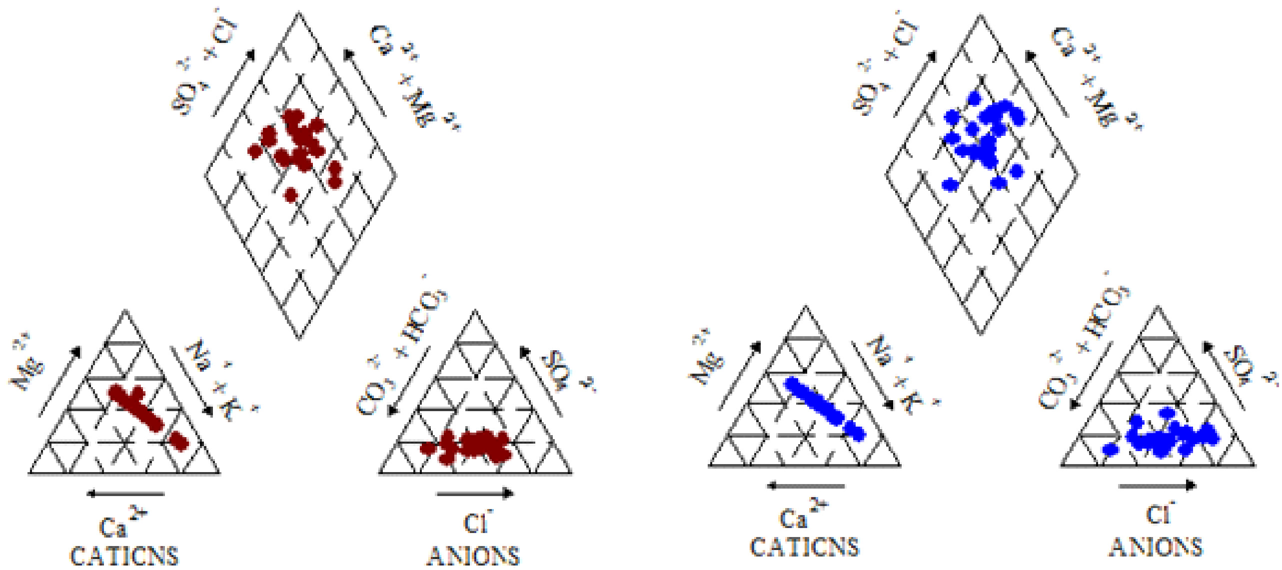



Figure 5: (c) Piper trilinear diagram for samples on granitoids, (d) Piper trilinear diagram for samples on migmatite-gneiss complex

When compared with the classification diagram of the Piper trilinear plot shown in figure 6 most of the water samples are of the mixed type of Ca-Mg-Cl and Na-$HCO_3$-Cl with none of the cation-anion pair being dominant in the groundwater.

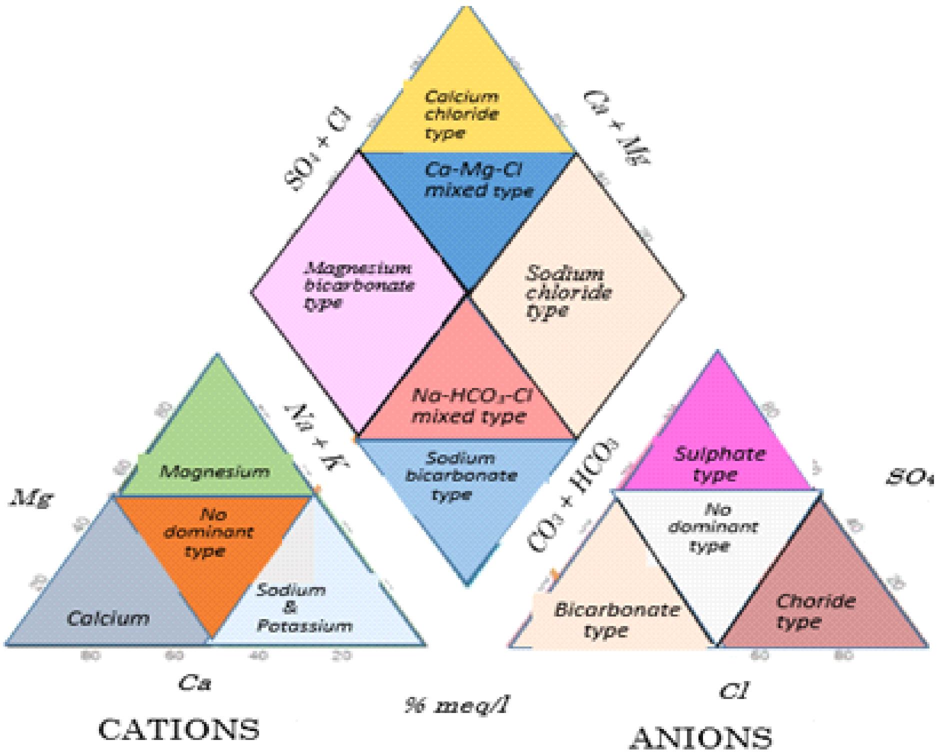
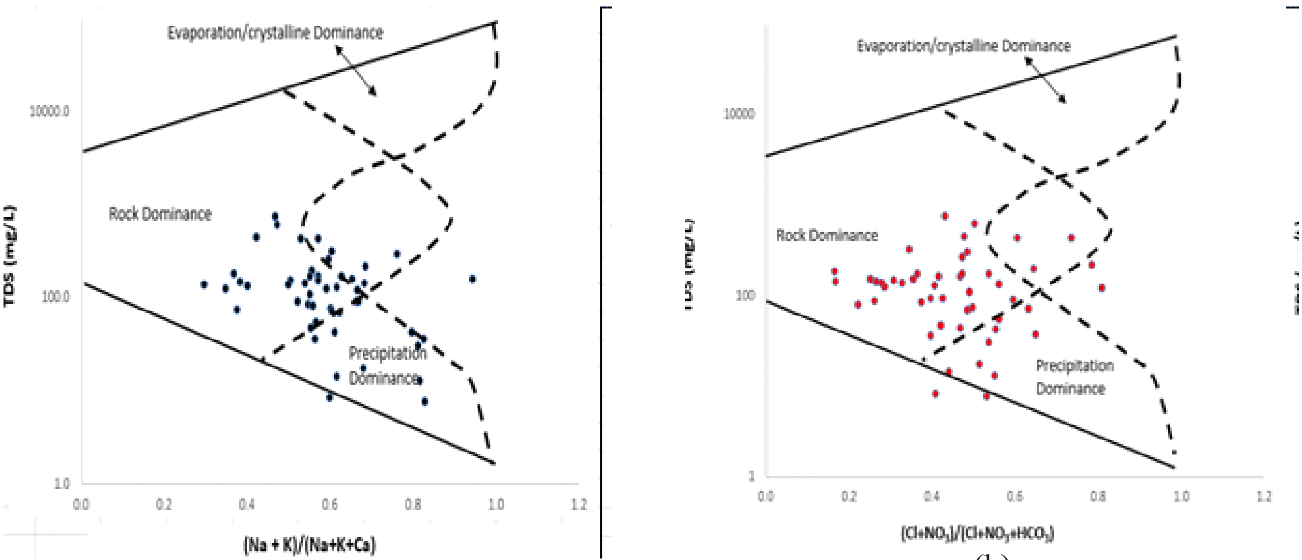



Figure 6: Classification diagram of the Piper trilinear plot

### 4.3 Mechanism Controlling Groundwater Quality

The ratios of major cations (Na, K and Ca) and the major anions (Cl, $NO_3$ and $HCO_3$), plotted against the total dissolved solids (TDS) in the Gibbs diagram (figure 7) show most of the water samples irrespective of formation fall within the rock dominance region. This shows that rock-water interaction as a result of rock weathering is the dominant mechanism controlling groundwater quality in the FCT. Some of the samples fall within the precipitation dominance which means that the chemistry of rainwater also controls the quality of groundwater in the region.




(a) (b)

Figure 7: Gibbs diagram showing the ratio (a) Na+K/(Na+Ca) (b) (Cl+$NO_3$)/(Cl+$NO_3$+$HCO_3$) as function of TDS

### 4.4 Evaluation of Health Risks due to Heavy Metals

The hazard index (HI), which is an indication ofthe health risks associated with ingestion of heavy metals in groundwater, determined for the concentrations of chromium, lead, cadmium and arsenic in the water samples in the study area ranges between 0.0 and 0.6. Since the maximum value of HI ? 1, there is no significant risk of non-carcinogenic effect of drinking the groundwater of FCT.

## 5 CONCLUSION

The result of fifty (50) groundwater samples from FCT, Abuja analysed by the National Water Resources Institute, Kaduna in 2016 under the programme "National Assessment of Drinking Water Quality Project" was used to characterise the groundwater resources in the six area councils of the FCT on the basis of rock types, determine the mechanisms controlling groundwater quality and determine the hazard index and possible health risk (if any) associated with ingesting heavy metals in the groundwater in the study area. The concentrations of the physico-chemical parameters of all the samples are within the maximum allowable limits of WHO and NSDWQ, making the water suitable for domestic use. The geochemical evolution of the groundwater shows that the water is of mixed type of Ca-Mg-Cl and Na-$HCO_3$-Cl with none of the cation-anion pair being dominant in the groundwater. The dominant mechanism controlling groundwater quality in the area is weathering of rocks, and to a small extent, the chemistry of rainwater falling in the area. The hazard index, which is an indication ofthe health risks associated with ingestion of heavy metals in groundwater was determined using the concentrations of chromium, lead, cadmium and arsenic in the water samples in the study area. The hazard index ranges in value between 0.0 and 0.6. Since the maximum value is less than 1, the ingestion of the groundwater in the study area poses no significant risk of non-carcinogenic effect to the consumers.

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