APPLICATION OF ENVIRONMENTAL ISOTOPES IN ELUCIDATING GROUNDWATER RECHARGE IN ABUJA, NORTH-CENTRAL NIGERIA

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ABSTRACT

The study area covers an area of about 5,000Km^2 in the central part of the Federal Capital Territory, Abuja, Nigeria, stretching along a NE–SW axis, cutting across geological, geomorphological and geopolitical boundaries of the territory. The aquifer systems in the study area are formed by weathered and fractured basement except in the southwestern part, which is formed by the sandstones of the Bida Basin. Eleven groundwater and one rain water samples were collected and analyzed for stable isotopes of deuterium (^{2}H) and Oxygen-18 (^{18}O) and radioactive isotope of tritium (^{3}H), according to standard methods. Results of isotope analyses revealed that the measured $\delta\ ^2$H values of the groundwater samples range from -17.1 to -14.3‰ while that of $\delta\ ^{18}$O range from -3.53 to -2.59‰. The $\delta\ ^2$H and $\delta\ ^{18}$O diagram shows that the water types originated from precipitation as the samples plot around the Global Meteoric Water Line (GMWL) with a deuterium excess in the range of 10 ± 2.7. This indicates similar recharge conditions and an isotopic enrichment by evaporation. Tritium (^{3}H) concentration for the groundwater samples varies from 2.3 to 5.0 TU with a mean of 3.56TU while that of the only rainwater sample was 4.85 TU. Applying qualitative age categorization, the range of tritium values depicts active recharge and recent groundwater.

***Key words**: Environmental Isotopes, Groundwater, Recharge, Abuja, Nigeria*

1. Introduction

The availability of clean fresh water is one of the great issues facing mankind today, in some ways the greatest, because problems associated with it affect the lives of many millions of people (Geyh, 2000). Since in many areas of the world relevant long-term data on water resources are missing, the traditional and isotope methods in combination with mathematical modelling often answer pressing questions about groundwater origin, chemical reactions, fluxes, ages and mixing processes occurring in reservoirs, naturally and caused by man. Only on this basis can relevant strategies for exploration, exploitation and protection of subsurface waters be developed (Seiler, 2000).

Water isotope hydrology addresses the application of isotopes that form water molecules. These are the oxygen (^{16}O, ^{17}O, ^{18}O) and hydrogen (^{1}H, ^{2}H, ^{3}H) isotopes. These isotopes (unlike other tracers of "water" such as Cl^-, which are still widely used) are ideal tracers of water sources and movement because they are constituents of the water molecule (Akiti, 2000).

The changes in chemical composition of meteoric water recharging the aquifer will depend on factors such as soil-water interaction, residence time, congruent and incongruent dissolution of mineral assemblages, sea water intrusions and anthropogenic impacts. These factors would give rise to different water chemistry and hence different aquifer characteristics (Dapaah-Siakwan and Gyau-Boakye, 2000; Helstrup *et al.*, 2007; Edmunds and Shand, 2008).

In groundwater catchments where barrier boundaries and inputs are well defined, interpretation of environmental isotopes record of precipitation, surface water and groundwater, coupled with available information on hydrochemical characteristics of groundwater will provide a detail picture of the groundwater system (Kendal and McDonnell, 1988).

Furthermore, hydrogeochemical and isotopic methods have been successful as economical ways to study local and regional groundwater systems, for example to determine groundwater interactions in the arid and semi arid environments (Schurch and Vuataz, 2000); to identify sources of groundwater (Abd El Samie and Sadek, 2001; Matter *et al.*, 2006; Plummer *et al.*, 2004; Stimson *et al.*, 2001); to evaluate the quantity of groundwater recharge (Abu-Jaber and Wafa, 1996; Mc Conville, 1999,; Negrel *et al.*, 2003; Wood and Sanford, 1995); and to research the interaction of different waters such as deep and shallow groundwater (Dassi *et al.*, 2005), surface and groundwater (Negrel *et al.*, 2003; Amadi *et al.*, 2014), and the replenishment of groundwater (Kendall and Mc Donnell, 1998; Zhang *et al.*, 2005; Al-Charideh and Katta, 2016).

Hydrological and hydrogeological information as well as groundwater monitoring data are available for some parts of Nigeria (Alao and Ige, 2003; Adelana and Olasehinde, 2005; Adelana *et al.*, 2008; Amadi *et al.*, 2015). These have formed the main input to clarify the hydrogeological systems in most regions of the country. Most of the isotope studies in Nigeria have been related to the evaluation of recharge mechanism especially in the semi-arid areas of northern Nigeria (Geyh and Wirth, 1980; Oteze, 1989; Onugba *et al.*, 1989, Mbonu and Travi, 1994,; Tijani *et al.*, 1996; Goni and Edmunds, 2001; Adelena *et al.*, 2002; Tijani, 2008).

The increasing usage of water for drinking and industrial purposes has geared up the interest of hydrogeological investigations in natural recharge and movement of fossil groundwater in the last four decades (Adelana and Olasehinde, 2004). In one of the pioneering isotopic research in northwestern Nigeria, Geyh and Wirth (1980) conducted groundwater dating of the confined aquifer of the Gwandu formation with the aim of determining the groundwater velocity to estimate the rate of recharge and confirm the direction of flow.

n the Federal Capital Territory, Abuja, hydrogeochemical methods have been used to determine groundwater quality. There is no comprehensive monitoring network of the groundwater systems to evaluate its past, current and future status for sustainable groundwater management and this is what the present study attempt to address through isotope technique. The objectives of the study are to determine the recharge sources, estimate age and evaluate isotopic signatures of groundwater in the central portion of the Federal Capital Territory, Abuja.

2. The Study Area

2.1 Physical Setting

The territory was created in 1978, following the decision to relocate the nation's capital away from Lagos in the southern coastal area to a more central location within Nigeria, devoid of domination by any of the major ethnic groups (Figure 1). The factors considered for the location of the "new" capital were justified by the Federal Government in Decree No. 6 of 1976 (FCT Handbook, 1994).

The area of study is located in the central part of the Federal Capital Territory, Abuja, Nigeria (Figure 2), stretching from the northeast to the southwest of the territory, along a diagonal axis. The Federal Capital Territory lies approximately between longitudes 6^0 46' and 7^0 37'E and latitudes 8^0 21' and 9^0 18' N. 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 bounded by Nasarawa State to the east, Kaduna State to the north, Niger State to the west and Kogi State to the south (Figures 1.1 and 1.2).

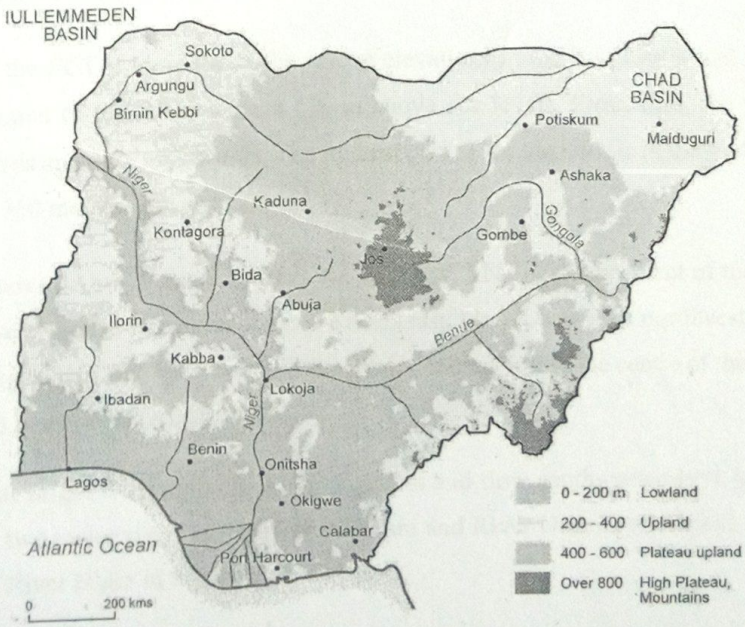


Figure 1: Map of Nigeria showing location of Abuja

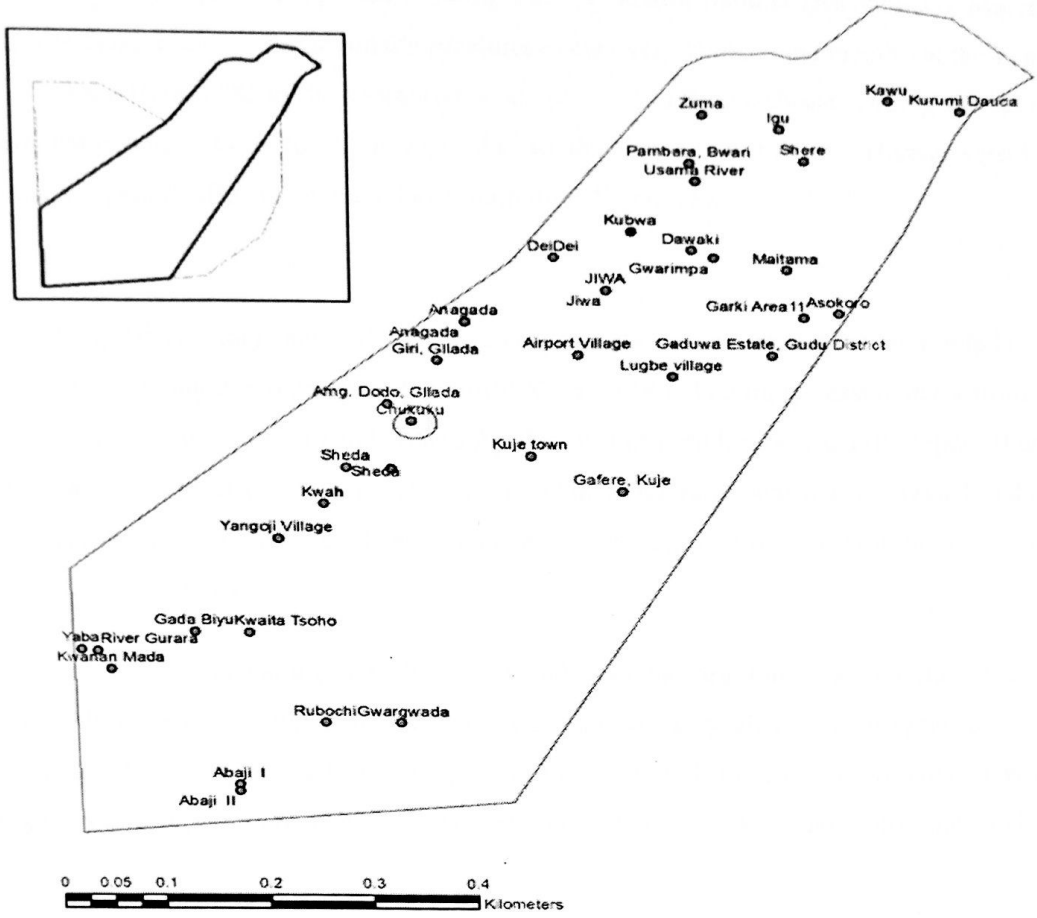


Figure 2: Map of the study area within the FCT showing sampling locations

The topography of the FCT is varied with the lowest elevations in the Territory found in the extreme south-west at the floodplains of the River Gurara (76 m above sea level). From here, the land rises irregularly eastwards, northwards and northwestwards. The highest part of the territory is in the northeast where there are many peaks above 760 metres above sea level.

Hills occur as clusters and long ranges all over the Territory. The most prominent of these include 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 (ABU, 1978).

The rivers take their origin from the hills in the northeast and flow southwesternly to join the south flowing River Gurara. The two major rivers are the River Gurara and River Usuma, which join at Nyimbo village to form a tributary of River Niger in the south.

2.2 Climate, Rainfall and Vegetation

The FCT records its highest temperature during the dry season months (November - March), which are generally cloudless. Extreme maximum temperatures occur everywhere in the vicinity of the Territory in these months and vary from 37^0C in the southwest to about 30^0C in the northeast. During the rainy season, the maximum temperature drops to about 27^0C due to the dense cloud cover. Human sensibility to these temperatures is greatly affected by the relative humidity (Yaya, 2006).

The Federal Capital Territory exemplified its character as between the zone of double rainfall maximum to the south and that of a single maximum to the north (Yaya, 2006). The rainy season starts from March on the southern boundary of the Territory and around April in the northern limits. The rains taper off around October in the north and November in the south. Thus, the duration of the rainy season is between 190 days in the north and 240 days in the southern parts of the Territory. The annual total rainfall is in the range of 1100 mm to 1600 mm (CIWAT, 2010).

Two major types of vegetation, namely, forest and savanna, are found within the FCT. The forest is predominantly of woody plants, from which grasses are virtually absent. Two types of forest have been identified on the basis of both topographical locations and differences in characteristics including physiognomy and floristic composition. They are rain forest and riparian vegetation complex (FCT Handbook, 1994).

2.3 Synopsis of the Geology

The description of the geology of the study area has variously been attempted in the works of Truswell and Cope (1963); Oyawoye (1972); Mc Curry (1970, 1976); Turner (1971); ABU (1978); Alagbe (1979) and Adelana *et al.* (2008). The study area is underlain by Precambrian rocks of the Nigerian Basement Complex, which cover about 85% of the land surface and sedimentary rocks, which cover about 15% of the territory in the southwestern part (Figure 3).

The major lithologic units found 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

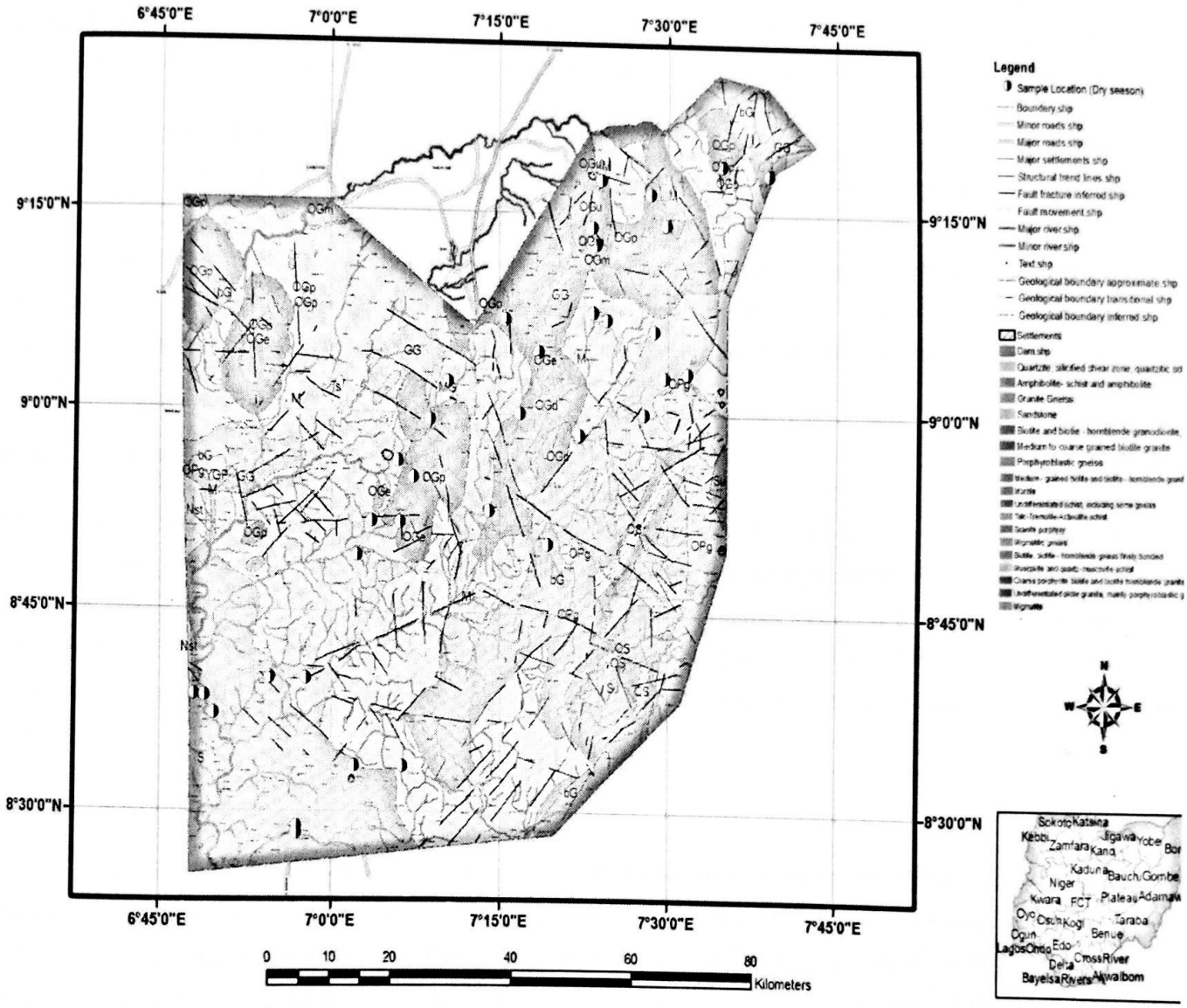


Figure 3: Geological map of FCT, Abuja, showing sample locations (Geological map modified after NGSA, 2004)

3. Materials and Methods

Eleven groundwater samples were collected at the peak of dry season (April, 2009) while one rainwater sample was collected in October, 2009, for isotope analyses using standard methods. The analyses were conducted at Activation Laboratories, Canada. For the determination of oxygen-18 and deuterium, stable isotope ratio mass spectrometer, Finnigan MAT 251 was used. Oxygen isotopes ($\delta^{18}O$) are determined by conventional CO_2 - H_2O equilibration method (Epstein and Mayeda, 1953). CO_2 is added to a vessel containing a surplus of the water sample. The vessel is sealed and emerges to facilitate CO_2 - H_2O equilibration. Equilibration time is 48

hours, long enough to equilibrate. The equilibrated sample is extracted on a vacuum line and cryogenically purified. Isotopic data are reported in the standard deviation from V-SMOW (Vienna Standard Mean Ocean Water). The CO_2 - H_2O equilibration factor is 1.0412. External reproducibility is $\pm$ 0.014‰.

Deuterium isotopes (δ^2H) are determined on 3 µl quantities of water using the uranium reduction method (Actlabs, 2010). Water samples are aliquoted with a microsyringe and ejected into a finger on a gas extraction line. The finger is heated to ensure evaporation of all the water. The water is reduced over hot uranium metal (750°C) and the resulting H gas collected on charcoal at -19.6 °C. Data are corrected for $^3H^+$ production in the ion source and reported in the standard delta notation as per mil deviation from V-SMOW. External reproducibility is $\pm$2.3‰ (1σ) based on repeat analysis of Cambrian Formation Water Standard (CFW) (Actlabs, 2010).

Radioactive Isotope (Tritium) Analysis

Tritium measurements (counts per minute {cpm}) are converted directly into absolute concentrations. A Canberra – Packard Pico-fluor LLT (low level tritium) is used, which has a high carrying capacity for water with high efficiency and low background characteristics. The laboratory standard is NBS-4361 tritium reference material diluted with background water which is then calibrated to NB-4926C. The background water is from a well with radiocarbon activity older than 3500 years and a conductivity of less than 300 µmho (Actlabs, 2010).

4. Results and Discussion

For the present study, a total of eleven ground water samples and one rain water sample were collected and analyzed for stable (^{18}O and ^2H) and radioactive (^3H) isotopes. The results of the stable isotopic composition, in δ - notation, are presented in Table 1. Values are reported in per mill (‰) with reference to V – SMOW (Vienna Standard Mean Ocean Water). External reproducibility is $\pm$ 0.14‰ for $\delta^{18}O$ and $\pm$ 2.3‰ for δ^2H.

Table 1: Results of physical properties and environmental isotope measurements in the study area

Locality	Long.	Lat.	Elev. (m)	Date	Depth (m)	pH	T °C	D.O. mg/l	E.C. µS/m	TDS g/l	δ^2H	$\delta^{18}O$	d-ex δ	^3H (TU

1	Zuma	07^0 24.09'	09^0 17.48'	590	10.04.09	24.8	6.1	26.9	4.6	110	70	-15.3	-3.36	12.25	2.3
3	Kawu	07^0 34.77'	09^0 18.66'	736	10.04.09	42.5	6.0	27.7	5.4	90	50	-15.5	-3.29	11.47	3.3
6	Pambara	07^0 23.33'	09^0 13.95'	520	10.04.09	41.2	6.4	28.6	7.1	31	200	-14.3	-3.24	12.26	4.0
9	Anagada	07^0 10.45'	09^0 02.38'	319	10.04.09	24.7	6.7	29.6	6.71	240	140	-16.9	-3.53	12.04	4.2
15	Gaduwa estate	07^0 27.91'	09^0 00.05'	397	12.04.09	17	5.5	28.2	6.2	160	100	-15.0	-3.15	10.83	3.1
18	Gafere, kuje	07^0 19.29'	08^0 50.77'	340	12.04.09	39.9	6.3	29.7	6.7	160	90	-15.0	-3.25	11.65	3.7
20	Yangoji	06^0 59.60'	08^0 46.73'	176	12.04 09	30.5	6.7	30.5	4.0	300	190	-16.5	-2.91	7.36	2.5
26	Gada biyu	06^0 54.63'	08^0 39.99'	82	13.04.09	8.5	5.1	29.5	5.3	320	200	-17.4	-3.26	9.33	3.6
27	Kwanan mada	06^0 49.75'	08^0 37.25'	86	13.04.09	50.5	5.5	30.5	5.9	30	20	-15.0	-3.13	10.66	3.5
30	Abaji 1	06^0 56.97'	08^0 28.87'	150	13.04.09	60	5.1	28.6	6.5	10	10	-17.4	-3.37	10.23	5.0

34	Maitama	07⁰ 28.79'	09⁰ 06.23'	533	15.04.09	42.5	6.7	28.3	6.0	100	60	-16.4	-2.59	4.83	4.0
R18	RainwaterGaduwa	07⁰ 27.91'	09⁰ 00.05'	397	18.10.09	-	6.5	22.7	8.5	10	10	12.3	1.23	2.21	4.85

Long.= Longitude, Lat.= Latitude, T= Temperature, E.C.= Electrical conductivity, TDS= Total dissolved solids, ^{2}H= deuterium, ^{18}O= Oxygen-18, d-ex= Deuterium excess, ^{3}H= Tritium, TU= Tritium Unit, S/N= Sample Number, all groundwater samples from boreholes except Gada biyu (hand-dug well).

Limited number of sampling for isotope analysis was done due to accessibility and cost. Groundwater samples were collected in April, 2009 at the peak of the dry season while rainwater sample was collected in October, 2009. Data interpreted were compared with the isotope measurements from precipitation in Kano for the period 1961-1973 (Onugba *et al.*, 1990). The relationship between $\delta\,^{18}O$ and $\delta\,^{2}H$ is plotted (Figure 4) alongside with the global meteoric water line (GMWL). Such a plot usually reveals indication about recharge source(s) of groundwater system as well as possible evaporation effect (Tijani and Abimbola, 2003; Al-Charideh and Kattaa, 2016). The measured $\delta\,^{2}H$ values of the analysed groundwater samples range from -17.4 to -14.3‰ with an average value of -15.88 ‰ while that of $\delta\,^{18}O$ range from -3.53 to -2.59 ‰ with an average of -3.18 ‰ (Table 1). It can be observed that the stable isotope composition of groundwater in the study area are depleted in both oxygen -- 18 and deuterium values with respect to the standard while $\delta\,^{18}O$ and $\delta\,^{2}H$ for rainwater are 1.23 and 12.3 ‰, respectively, compared to that of seawater ($\delta\,^{2}H = 0$ ‰ and $\delta\,^{18}O = 0$ ‰) and also plotted close to the GMWL as defined by the equation:

$$\delta^{2}H = 8 \times \delta^{18}O + 10 \qquad \text{----------(1)}$$

The values of deuterium excess (d-excess), calculated from the relation:

$$d = \delta^{2}H - 8\,\delta^{18}O \qquad \text{---------- (2)}$$

are generally in the range of 10 ± 2.7‰, i.e. close to 10 (Table 1). Exception to this, however, is the sample from Maitama with relatively lower deuterium excess value of 4.83‰ compared to other samples which may be attributed to the local geology of the area as well as evaporation effect. The deuterium excess reflects the conditions that lead to kinetic isotope fractionation between water and vapour during primary evaporation in

the oceans (Dansgaard, 1964). This number also shows the extent of deviation of a given sample from the meteoric water line (Gibrilla *et al.*, 2010). The low deuterium excess observed in this location is probably related to enrichment due to kinetic evaporation as well as the influence of rock-water interaction. The influence of other physical factors such as density – duration of rainfall (amount effect) and latitude – altitude effects could also be significant.

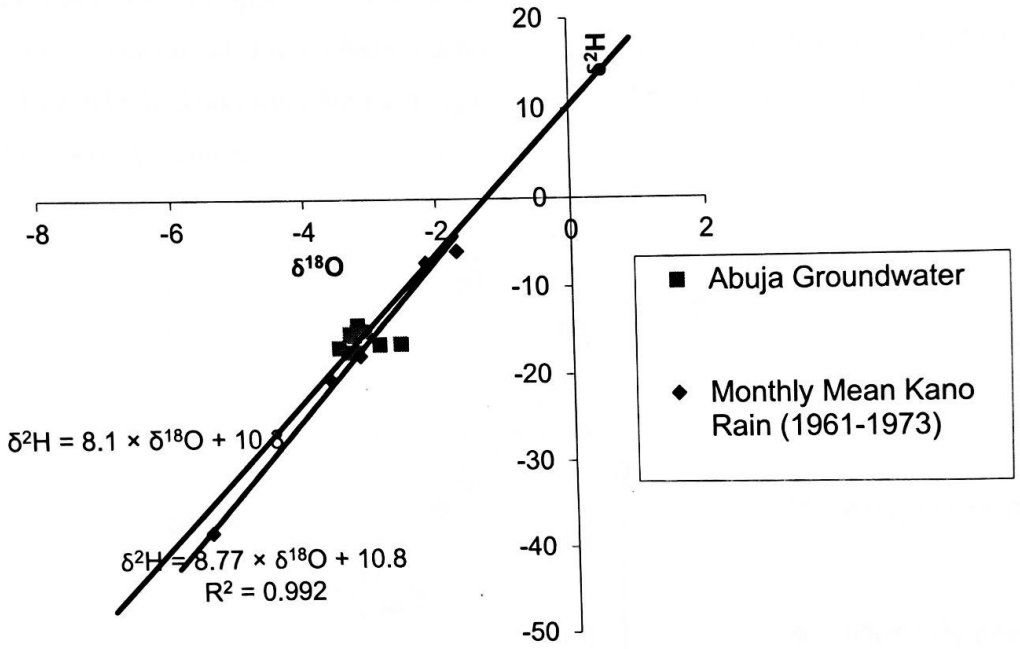


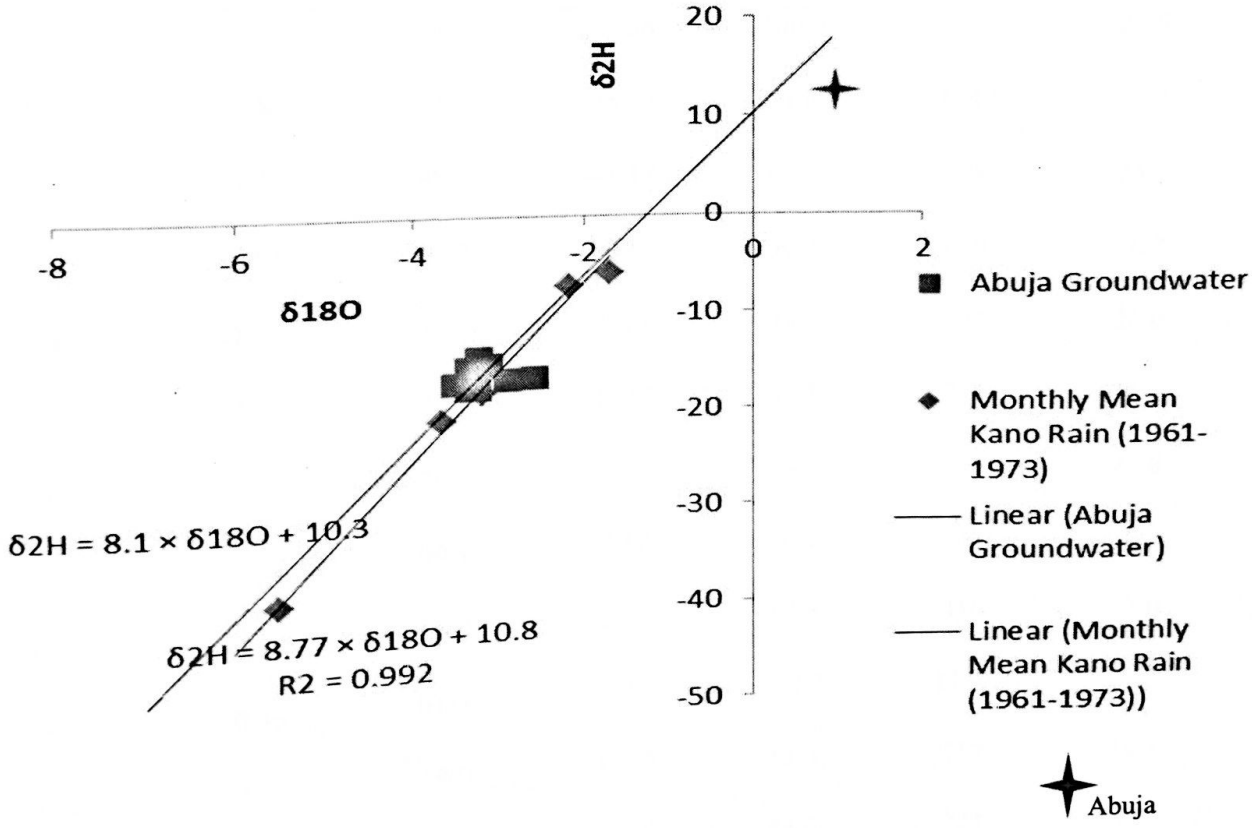
Figure 4: A plot of $\delta^{18}O$ vs $\delta^{2}H$ for Abuja groundwater samples (present study) and monthly mean of precipitation for kano (Onugba *et al.*, 1990).

4.1 Stable Isotopes in Precipitation and Groundwater

Isotopes in precipitation have been measured monthly for samples collected at Kano Airport (N 12.05^0, E 8.53^0, altitude 476 m a.s.l.) by the International Atomic Energy Agency (IAEA) from 1961 to 1973 (Onugba *et al.*, 1990). Kano has one season rainfall (May – September: >50 mm/month) with temperature range from 21.3 to 30.9^{0}C); and relatively dry period (November – April: <0.1 – 11 mm/month).

Figure 5 shows the plot of $\delta^{2}H$ and $\delta^{18}O$ values for groundwater and rain water samples in the study area with the long-term mean of monthly precipitation at Kano, north-central Nigeria. The plot of $\delta^{2}H$ and $\delta^{18}O$ for

meteoric water in Kano is the closest isotopic measurement in Nigeria that can be compared to Abuja groundwater as shown in the Figure 5. The isotopic composition of the studied groundwater is low in δ^2H and $\delta^{18}O$. However, these depleted values plot around the Global Meteoric Water Line (GMWL), which suggest that the groundwater in the area is recharged from meteoric source. In Table 2, the data for annual weighted mean values for δ^2H and $\delta^{18}O$, the corresponding annual precipitation and mean temperature for the period 1961 – 1973 at Kano are presented. The long-term (1967 – 1973) weighted mean values of $\delta^{18}O$ and δ^2H for rainfall are – 3.3 and – 17.9‰, respectively (Onugba *et al.*, 1990). The weighted monthly mean of $\delta^{18}O$ and δ^2H are – 3.19% and - 15.9% respectively. The local meteoric water line (LMWL) obtained using the average monthly precipitation measured at Kano Airport is not significantly different from the Global Meteoric Water line ($\delta^2H = 8.1 \times \delta^{18}O + 10.3$) as earlier shown in Figure 4. The findings further confirmed that the groundwater in the area is of meteoric source.



rainwater sample

Figure 5: Plot of Oxygen-18 vs Deuterium for the groundwater and rainwater samples (note the isotopically enriched rainwater sample

However, all these data plot around the Global Meteoric Water Line and showed relatively higher deuterium excess, d (calculated from the equation defined by Dansgaard, 1964). The local values of the weighted yearly means, as well as the long-term average from 1961 – 1973, plot almost on the global meteoric water line (GMWL) following the relation:

$$\delta\,^{2}H = 8.77 \times \delta^{18}O + 10.8 \qquad \text{----------(3)}$$

Both slope and D – excess are comparable to the Global Meteoric Water Line. The fact that the groundwater samples plot around the GMWL can be explained by fairly low precipitation and moderately high evaporation occasioned by the vegetation and climate of the area which results to subsequently less depleted isotopic groundwater.

The d–excess calculated from the weighted average values is 10.3‰, thereby indicating relatively lower deuterium content in the groundwater regime in the area. The mean isotopic concentration of the rain water from which the groundwater was derived suggests that the mean $\delta^{18}O$ of rainfall events resulting in recharge is about – 3.3‰ VSMOW (IAEA, 1979).

4.2 Radioactive Tritium Isotope Profile

Tritium values from 11 groundwater samples (Table 3) vary from 2.3 to 5.0 TU with a mean of 3.56 TU while that of the rain water sample from the study area is 4.85TU. The apparent qualitative age of groundwater is considered to be the amount of time determined from an age-dating tracer that has elapsed from the time water lost contact with the atmosphere. Therefore, the groundwater could be classified as a mixture of recent water with old groundwater and groundwater that has been subjected to radioactive decay.

With respect to the concentration profile of tritium as shown in Table 3, it might be postulated that groundwater in the study area have a narrow range of tritium values (2.3 – 5.0 TU). This narrow range of tritium enrichment should reflect the effect of recharge inputs from rainwater. The tritium value for the rainwater sample is 4.85 TU. This incidentally lies within the range of tritium values for the groundwater and thus indicates groundwater with evidence of mixing with meteoric water. This is clearly an indication of recent groundwater system dominated by recharge from recent precipitation.

Furthermore, this indicates the importance of direct recharge water contribution to groundwater storage through the fractures and faults that tend to control the surface drainage network in the basement rock area. The sandstone formation in the sedimentary area is characterized by highly porous and permeable sandy horizons, which provide direct and easy access to percolating rainwater. Table 3 shows the summary of

isotopic compositions along with hydrochemical water type and geology. The range of tritium concentration from both the basement and sedimentary aquifers varies narrowly, with samples from the basement aquifers having tritium concentration varying from 2.3 – 4.2 TU while those from the sedimentary aquifer have tritium concentration from 3.5 – 5.0 TU. The overlap and similarity in tritium concentration (Table 3) in both the basement and sedimentary aquifers probably indicate similar recharge sources for the aquifers. Applying the qualitative age categorization proposed by Clark and Fritz (1997), the range of tritium values depicts active recharge and mixture of sub-modern and recent groundwater.

Therefore, taking the conventional wisdom that elevated tritium (^3H) content in groundwater points to active recharge (Diop and Tijani, 2008) and that the chemistry of groundwater of the study area is marked by mixed spatial distribution of tritium content (Table 3), probably resulting from varied rainfall pattern and amount across the area. Groundwater undergoing evaporation will have a positive correlation between $\delta^{18}O$ and conductivity. In the diagram of $\delta^{18}O$ versus conductivity (Figure 6), it was observed that a negative correlation was obtained with $R^2 = 0.005$. In addition, an increase in electrical conductivity (EC) values takes place without significant changes in isotopic composition (Figure 7), which may be due to mineralization. The groundwater samples show a relative enrichment of the heavier isotopes without a simultaneous increase in EC, thus confirming that the groundwater appears to be recharged by moderately high evaporated isotopically enriched water on the surface or in the unsaturated zone.

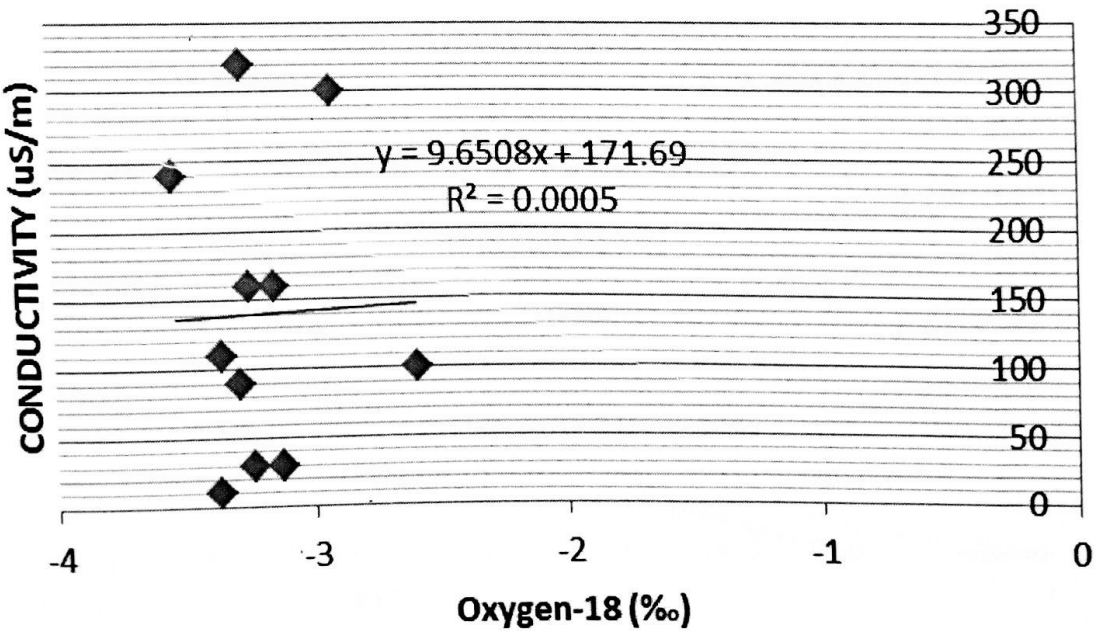


Figure 6: A plot of electrical conductivity (EC) versus Oxygen-18

Table 3: Summary of the Geology and Isotopic Composition in the study area

Sample No.	Locality	Long.	Lat.	$\delta^{2}H$ ‰o	$\delta^{18}O$ ‰o	d-excess, ‰o	^{3}H (TU)	Geology
1	Zuma	07^{0} 24.09'	09^{0} 17.48'	-15.3	-3.36	12.25	2.3	Granite
3	Kawu	07^{0} 34.77'	09^{0} 18.66'	-15.5	-3.29	11.47	3.3	Granite
6	Pambara	07^{0} 23.33'	09^{0} 13.95'	-14.3	-3.24	12.26	4.0	Granite
9	Anagada	07^{0} 10.45'	09^{0} 02.38'	-16.9	-3.53	12.04	4.2	Granite
15	Gaduwa estate	07^{0} 27.91'	09^{0} 00.05'	-15.0	-3.15	10.83	3.1	Mig/gneiss
18	Gafere, kuje	07^{0} 19.29'	08^{0} 50.77'	-15.0	-3.25	11.65	3.7	Mig/gneiss
20	Yangoji	06^{0} 59.60'	08^{0} 46.73'	-16.5	-2.91	7.36	2.5	Mig/gneiss
26	Gada biyu	06^{0} 54.63'	08^{0} 39.99'	-17.4	-3.26	9.33	3.6	Metasediments
27	Kwanan mada	06^{0} 49.75'	08^{0} 37.25'	-15.0	-3.13	10.66	3.5	Sandstone
30	Abaji 1	06^{0} 56.97'	08^{0} 28.87'	-17.4	-3.37	10.23	5.0	Sandstone
34	Maitama	07^{0} 28.79'	09^{0} 06.23'	-16.4	-2.59	4.83	4.0	Granite

R18	Rainwater Gaduwa	07^0 27.91'	09^0 00.05'	12.3	1.23	2.21	4.85	---

Long.= Longitude, Lat.= Latitude, ^{2}H= deuterium, ^{18}O= Oxygen-18, d-excess= Deuterium excess, ^{3}H= Tritium, TU= Tritium Unit, all groundwater samples from boreholes except Gada biyu (hand-dug well), Mig/gneiss= Migmatite-gneiss.

4.3 Deuterium Excess (d-excess)

The deuterium excess (d-excess) reflects the conditions that lead to kinetic isotope fractionation between water and vapour during primary evaporation in the oceans (Dansgaard, 1964). This number also shows the extent of deviation of a given sample from the Global Meteoric Water Line (Gibrilla *et al.*, 2010). The groundwater deuterium excess values range from 4.83 to 12.26 ‰, while that of the only rain water sample was 2.21 ‰. As the δ^{18}O increases (becomes more enriched), the deuterium excess in all the samples decreases gradually (Figure 7). This observation can be partly attributed to the dilution of the groundwater with rainfall, which could increase the d-excess (Tijani and Abimbola, 2003; Yuan and Miyamoto, 2008).

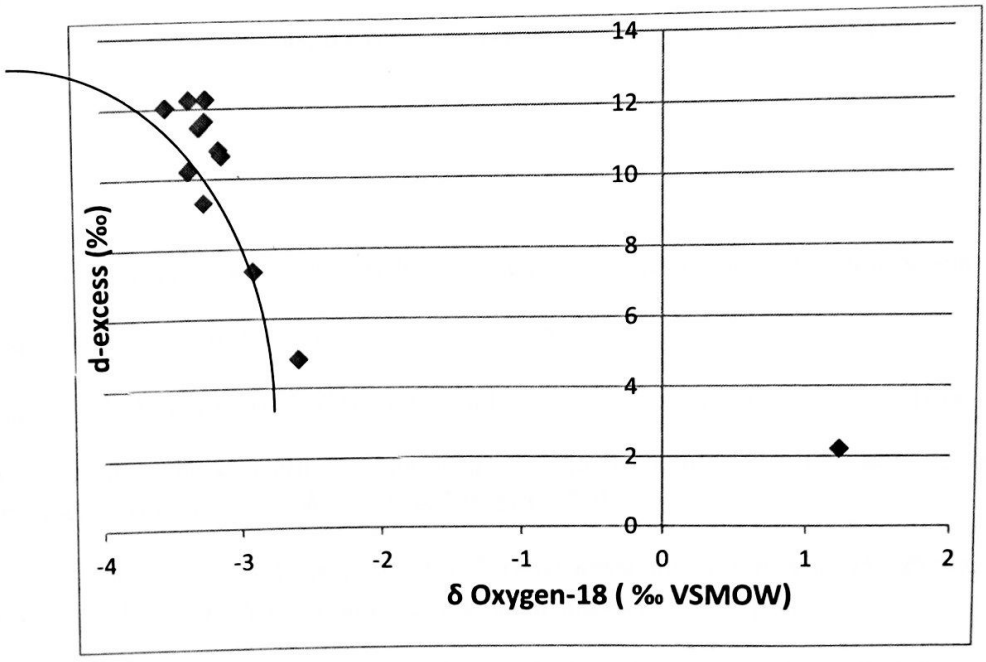


Figure 7. A plot of deuterium-excess (d-excess) versus Oxygen-18 (δ^{18}O).

5. Conclusion and Recommendation

The results of stable isotope analysis (Table 3) carried out on the sampled groundwater revealed $\delta^{18}O$ values as varying from -3.53 to -2.59 ‰, with an average of -3.18‰. The $\delta^{2}H$ values range from -17.4 to -14.3‰, with an average of -15.88‰. The negative values of oxygen-18 (^{18}O) and deuterium (^{2}H) are indicative of depletion of oxygen-18 and deuterium relative to the Vienna Standard Mean Ocean Water (VSMOW). The stable isotope composition relative to the Global Meteoric Water Line (GMWL) reveals important information on the groundwater recharge pattern. The plot of $\delta^{2}H$‰ against $\delta^{18}O$‰ of the analysed samples indicate a cluster around the GMWL given by the equation (Craig, 1961): $\delta^{2}H = 8\ \delta^{18}O + 10$.

The narrow variation in the tritium content of sampled groundwater could be a reflection of similar recharge sources for both the aquifers of the basement complex and sedimentary formations. The range of tritium content (2.3 – 5.0 TU) depicts active recharge and mixture of sub-modern and recent groundwater. Despite the spatial heterogeneity of geological and climatic conditions in the study area, this would probably suggest that the groundwater of the study area has received significant contribution from rainwater, which is responsible for the apparent tritium enrichment in the groundwater. The major possible recharge pathways in the study area are through topsoil and the loose, unconsolidated formation. Another possible recharge pathway is by direct infiltration through joints, fractures and faults in the Basement Complex parts of the study area.

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