

## MEASUREMENT OF $^{238}\text{U}$ , $^{232}\text{Th}$ AND $^{40}\text{K}$ IN BOREHOLES AT GOSA AND LUGBE, ABUJA, NORTH CENTRAL NIGERIA

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The purpose of this project is to evaluate the suitability of different sites as locations for obtaining underground water for consumption. The analysis of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  from rock samples from each layer of borehole at a depth of  $\sim 50$  m at Site A borehole, S3L1–S3L6 in Gosa and 40 m at Site B borehole, S4L1–S4L5 in Lugbe, Abuja, north central Nigeria is presented. The gamma-ray spectrometry was carried out using a high-purity germanium detector coupled to a computer-based high-resolution multichannel analyzer. The activity concentrations at Site A borehole for  $^{238}\text{U}$  have a mean value of  $26 \pm 3$ , ranging from  $23 \pm 2$  to  $30 \pm 3$  Bq  $\text{kg}^{-1}$ ,  $^{232}\text{Th}$  a mean value of  $63 \pm 5$ , ranging from  $48 \pm 4$  to  $76 \pm 6$  Bq  $\text{kg}^{-1}$  and  $^{40}\text{K}$  a mean value of  $573 \pm 72$ , ranging from  $437 \pm 56$  to  $821 \pm 60$  Bq  $\text{kg}^{-1}$ . The activity concentrations at Site B borehole for  $^{238}\text{U}$  have a mean value of  $20 \pm 2$ , ranging from  $16 \pm 2$  to  $23 \pm 2$  Bq  $\text{kg}^{-1}$ ,  $^{232}\text{Th}$  a mean value of  $46 \pm 4$ , ranging from  $43 \pm 4$  to  $49 \pm 4$  Bq  $\text{kg}^{-1}$ ,  $^{40}\text{K}$  a mean value of  $915 \pm 116$  and ranging from  $817 \pm 103$  Bq  $\text{kg}^{-1}$  to  $1011 \pm 128$  Bq  $\text{kg}^{-1}$ . It is noted that the higher activity concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$  are found in Site A at Gosa. Site B has lower radioactivity, and it is recommended that both sites are suitable for underground water consumption.

### INTRODUCTION

Naturally occurring radioactive materials (NORMs) such as uranium, thorium and potassium are found throughout the earth's crust, and they form a part of the natural background radiation to which all humans are exposed<sup>(1)</sup>. The presence of these (NORM) in soils, rocks, water and air, along with cosmic radiation results in continuous and unavoidable internal and external radiation exposures of all humans<sup>(2)</sup>. The NORMs in the earth or soils and water of an environment are present as progenies of  $^{238}\text{U}$  and  $^{235}\text{U}$  and  $^{232}\text{Th}$  isotopes distributed by natural geological and geochemical processes in addition to potassium  $^{40}\text{K}$ <sup>(3)</sup>. Extensive work has been carried out in many countries to evaluate the risks associated with NORMs<sup>(2, 4)</sup>. Natural environmental radioactivity and associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world. The specific levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area, and to the content in  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  of the rocks from which soils originate in each area<sup>(2, 5–7)</sup>.

Uranium occurs as a trace element in the Earth's crust and is typically present in the concentration of 1–10 ppm in granite and in clastic sediments of

granitic origin and thorium is typically present in concentrations ranging between 3 and 30 ppm in crustal minerals. Most thorium is found in sediment<sup>(8)</sup>, while the average concentration of potassium in crustal rocks is  $\sim 2.5\%$  with a range from 0.1 to 5% or more.

Terrestrial natural radionuclides of soils and rocks in Kinta District, Perak, Malaysia were reported with high activity concentrations of  $^{238}\text{U}$  and  $^{232}\text{Th}$  and low activity concentration of  $^{40}\text{K}$ <sup>(9)</sup>.

Generally, the underlying bed-rocks and minerals of the earth crust which to a large extent constitute the geology of a location are known to contain natural radioactive elements at varying concentrations. In 2006, during limited field investigation involving uranium in the subsurface at the Hanford Site's 300 area, unexpectedly, high concentrations of uranium were discovered in the groundwater samples collected at two of the four characterisation boreholes<sup>(10)</sup>.

Peterson *et al.*<sup>(11)</sup> estimated that  $\sim 650\,000$  m<sup>3</sup> of groundwater beneath the 300 area investigated are affected by uranium at the concentrations that exceed the drinking water standard of 30  $\mu\text{g ml}^{-1}$ .

In Nigeria, the case for conjunctive use of surface and groundwater supply, where available, to meet the ever-increasing demand cannot be over-emphasised. In the same vein, relating the available resources to demand, the population searching for water become

more acute. The World Health Organization and UNICEF report for 2012 ranks Nigeria the third most populous country without adequate water and proper sanitation<sup>(12)</sup>.

The study area (Abuja) had a master plan in 1979, which projected population figures in the region of 5.8 million people by 2026. The current population of Abuja is 2 759 829 (UNFPA, 2013). It has an area coverage of 713 km<sup>2</sup> (275.3 sq mi) and the density of 1091.9 km<sup>-2</sup> (2828 sq mi<sup>-1</sup>). The Abuja Water Board has a designed capacity with the pre-plan which is not in phase with the city growth in the recent times. The increase in demand for water has led to compulsory alternative source to defray the deficit. The majority of the water sources come from the borehole/aquifer-bearing formation of reasonable depths. The water has been consumed without treatment and during drilling processes; it cuts across many rock formations. The radioelements that exist in this rock formation like granite to some extent could contaminate the groundwater system through leaching and weathering processes. As a result, most of the public in the satellite towns and suburbs are not aware of the potential problems associated with aquifer-bearing rocks constituting radioactive elements. The objective of this study is therefore to determine the activity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in the lithological units to the aquiferous zone (groundwater-bearing rocks) of varying depths, 50 and 40 m in Gosa and Lugbe, respectively.

## GEOGRAPHICAL LOCATION OF THE STUDY AREA

### The location of the study area

The study areas are bounded by latitudes 8°53'N–9°13'N and longitudes 7°00'E–7°30'E. The towns where the boreholes sited were in the coordinates: latitude: 8°56'45.6"N and longitude: 7°13'26.2"E (Gosa) and latitude: 8°59'2.3"N and longitude: 7°23'7.8"E (Lugbe). They have become important because of the increasing population of the suburbs of Abuja. Many residents of the area embark on the development of private boreholes to augment public water supplies which are inadequate.

### Climate condition of Abuja

Abuja under the Koppen climate classification features a tropical wet and dry climate. The Federal Capital Territory Abuja, experience three weather conditions annually. This includes a warm, humid rainy season and a blistering dry season. In between the two, there is a brief interlude of Harmattan occasioned by northeast trade winds, with the main features of dust haze, intensified coldness and dryness. The rainy season begins in April and ends in October,

when daytime temperatures reach 28°C (82.4°F) to 30°C (86.0°F) and night time lows hover around 22°C (71.6°F) to 23°C (73.4°F). In the dry season, daytime temperatures can soar as high as 40°C (104.0°F) and night time temperatures can dip to 12°C (86.0°F). Even the chilliest nights can be followed by daytime temperatures well above 30°C (86.0°F). The high altitudes and undulating terrain of the Federal Capital Territory, Abuja act as a moderating influence on the weather of the territory. Rainfall in Abuja reflects the territory's location on the windward side of Jos plateau and the zone of rising air masses with the city receiving frequent rainfall during the rainy season from March to November every year (World Weather Information Service-Abuja, 2012).

## GEOLOGICAL AND GEOPHYSICAL INFORMATION OF THE STUDY AREA

### Geology and hydrogeology of the area

The area of study forms part of the basement complex of north central Nigeria, with lithological units falling under three main categories, which includes (1) undifferentiated migmatite complex of Proterozoic to Archean origin, (2) metavolcano-sedimentary rocks of Late Proterozoic age and (3) older granite complex of Late Precambrian–Lower Palaeozoic age, also known as Pan-African Granites. All these rocks have been affected and deformed by the Pan-African thermotectonic event. The detailed reports of the lithological description, age, history, structure and geochemistry of the basement complex of Nigeria are given in refs (13–18). The rocks are generally weathered into reddish micaceous sandy clay to clay materials, capped by laterite. The hydrogeology of the basement areas is simple since there is an inherent limitation to the occurrence of groundwater. However, where the regolith is thick, and there is a dense network of fractures, the potentials for the accumulation of groundwater in basement complex rocks may increase. Limitations of yield may be due to the fact that the aquifers are often localised. This makes the search for a feasible borehole site imperative in the area. Generally, the life span of boreholes is much lower in the area than in most areas that are underlain by porous sedimentary materials.

### Geophysical investigation

A geophysical investigation was conducted to locate the suitable sites for drilling and also the structures that control the aquifer and depth to the basement terrain groundwater. Twelve soundings were made in and around the study areas to choose the densely populated zone. The geology of Abuja, therefore, makes the groundwater conditions in the area very unpredictable and requires a thorough survey. Vertical

electrical sounding<sup>(19, 20)</sup> was carried out at 12 locations within and around the study area and the results integrated with the structural data generated from the hill shaded Shuttle Radar Topographic Mission data<sup>(21–24)</sup> to infer the subsurface layers and structures. The interpretation of the data obtained from the soundings revealed that six aquiferous geoelectrical layers overlie the fractured basement in some areas and three non-aquiferous layers overlie the fractured in south western part of the study area.

## MATERIALS AND METHODS

### Drilling boreholes

The boreholes were drilled with the help of a 30-ton capacity Rig machine with a compressor made of INGERSOL of 25-ton capacity. The rocks were clay and sand, and the medium was heterogeneous as the thickness of the different layers differed in the boreholes. The cutting method using the technical procedure was employed<sup>(25)</sup>.

### Sample inventory

The identification of boundaries between layers with noticeably different particle sizes using a visual manual logging method, record the thickness when the layer changes. The layer thickness change may range from <1 m to tens of metres. After boundary

of district layers have been clearly marked on plastic sock with an indelible felt-tipped pen, using a single entry for each layer.

- (1) Record the date the sample is logged and the initials of the logger.
- (2) Record the sample type. For this sample, record 'SL' to designate a geologically logged core segment, Site A borehole.
- (3) Determine and record the depth interval for each layer.
- (4) The two sites were Gosa (49–50 m) and Lugbe (39–40 m).

*Site A/Borehole A (S3):* Six samples were collected from the drilling of well (S3). In addition, labelled using borehole number and depth. Details about the samples are listed in Table 1.

*Site B/Borehole B (S4):* Five samples were collected from the drilling well of S4. Details about the samples are listed in Table 2.

### Sampling and sample preparation

A total of 11 samples collected were dried under the ambient temperature of 25–29°C for some weeks and sealed back into the plastic sock in Nigeria. They were transported from Nigeria to Universiti Teknologi Malaysia, Nuclear Laboratory. The samples were first dried at 105°C each overnight with oven made of Memmert, model Schutzart Din 40050-IP20

**Table 1. Depth and lithologic unit of Site A borehole.**

Sample ID	Depth (m)	Thickness (m)	Lithology description
S3L1	0–4	4	Sandy clay, reddish brown laterite top soil
S3L2	4–10	6	Sandy clay, fine to medium, reddish to yellow
S3L3	10–11.3	1.3	Clay sandy feldspar Yellowish brown pebbly
S3L4	11.3–18.5	7.2	Micaceous clayey, grey to black
S3L5	18.5–24	5.5	Sandy shinny greyish to black feldspar
S3L6	24–33	9	Fine medium shinny, quartz interbed, greyish ash feldspar

Coordinate (Lat: 8°56'45.6"N and Long: 7°13'26.2"E, GPS-Model: Extrex High Sensitivity 2000–2007 Garmin Ltd) was used for coordinate.

**Table 2. Depth and lithologic unit of Site B borehole.**

Sample ID	Depth (m)	Thickness (m)	Lithology description
S4L1	0–7	7	Laterite topsoil, yellowish brown
S4L2	7–16.8	9.8	Sandy clay, fine to coarse, brownish yellow
S4L3	16.8–27	10.2	Clayey sandy, brownish ash, fine grain feldspar
S4L4	27–39	12	Sandy micaceous, grey, interbedded with quartz feldspar
S4L5	39–40	1	Fine to coarse, ashy to grey

The drilling point coordinate (Lat: 8°59'2.3"N and Long: 7°23'7.8"E), GPS- Model: Extrex High Sensitivity 2000–2007 Garmin Ltd) was used for coordinate.

by Western Germany, crushed with the help of Bico Pulverizer MFD by Bico, Inc. UA Burbank California. After crushing of each sample, a high-pressure compressor air with a nozzle pipe was used to flush the remnant on the crushing machine and cleaned with the tissue to avoid cross-contamination before adding another sample. It was crushed to powder and passed through 250- $\mu\text{m}$  sieve mesh with the help of Sieve shaker made of IMK11 Ende Cott Ltd, UK. The fine powdered samples were homogenised, and carefully weighed using an electronic balance with a sensitivity of 0.01 g. The powdered samples were packed in standard 500-ml Marinelli beakers and labelled accordingly with an indelible marker. The samples were sealed and stored for 4 weeks to achieve secular equilibrium between radium and its progeny<sup>(26, 27)</sup>.

### Experimental method for gamma spectroscopy

Experiments were carried out using the gamma-ray spectroscopy facilities at the Nuclear Laboratory Faculty of Science, Universiti Teknologi Malaysia. The gamma-ray spectroscopy consists of a high-purity germanium (HPGe) detector with a counting efficiency of 20 %, with a resolution of 1.8 keV for 1332 keV gamma-ray emission of  $^{60}\text{Co}$ . The detector used in these measurements was a Canberra GC2018 with Genie-2000 software. The detector was cooled by liquid nitrogen and preamplifiers were placed inside a lead shield to reduce the background radiation<sup>(28)</sup>.

Under the conditions of secular equilibrium, the  $^{232}\text{Th}$  concentration was determined from the average of  $^{208}\text{Tl}$  using the 583-keV peak and  $^{228}\text{Ac}$  by using the 911-keV peak.  $^{238}\text{U}$  was determined from the average concentrations of the  $^{214}\text{Pb}$  by using the 352-keV peak and  $^{214}\text{Bi}$  by using the 609-keV peak<sup>(29, 30)</sup>. The 1460-keV peak was used to determine the concentration of  $^{40}\text{K}$ . Each sample was put into a shielded HPGe detector and measured for 21600 s. The background gamma-ray spectrum of the detection system was determined and was subtracted from the spectra of each sample.

The specific activity was determined by comparison with the IAEA standard samples S-14 (Thorium ore) and SL-2 (Lake Sediment). The IAEA standard samples S-14 and SL-2 were used as reference materials and were mixed with  $\text{SiO}_2$  in Marinelli beakers. The uranium and thorium content from S-14 are 29 and 610 ppm, respectively. A weight of 20 g from sample IAEA S-14 was thoroughly mixed with 100 g of  $\text{SiO}_2$  in a Marinelli beaker. Another Marinelli beaker contains only 100 g of  $\text{SiO}_2$  to estimate the background for standard samples. The IAEA standard sample SL-2 was used to calculate the specific activity of potassium. It has a specific activity of 240  $\text{Bq kg}^{-1}$ . A weight of 74.18 g of SL-2 was mixed with 100 g of  $\text{SiO}_2$  in a Marinelli beaker.

## RESULTS AND DISCUSSION

### Activity concentrations of $^{232}\text{Th}$ , $^{238}\text{U}$ and $^{40}\text{K}$ at Site A borehole S3L1–S3L6 in Gosa

The measured activity concentrations of  $^{40}\text{K}$ , nuclides from  $^{232}\text{Th}$  series ( $^{208}\text{Tl}$ ,  $^{228}\text{Ac}$ ) and  $^{238}\text{U}$  series ( $^{214}\text{Pb}$ ,  $^{214}\text{Bi}$ ) in the investigated rock samples are presented. The  $^{238}\text{U}$  activity concentrations were calculated as the arithmetic means of the activities of  $^{214}\text{Pb}$  and  $^{214}\text{Bi}$  isotopes. The  $^{232}\text{Th}$  and  $^{238}\text{U}$  concentrations are based on the  $^{228}\text{Ac}$  and  $^{226}\text{Ra}$  activity concentrations, respectively.

The Th/U ratio ranged from 5.77 to 9.02 is shown in Table 3. Sample S3L3 has the highest Th/U ratio of 9.02 and Sample S3L7 has the lowest Th/U ratio of 5.77. The Th/U ratio given by ref. (31) for the continental crust equals 1.2 and for granite is 1.8. At Site A borehole, the Th/U ratio is 7 and 5 times higher than the average value for the continental crust and granite, respectively. For example, in hornfel from the Death Bend area, Th/U equals 3, and the Th/U concentration ratio in rocks in the environs of Swieradow Zdroj varies between 1.5 and 3.2<sup>(32)</sup>.

In Table 3, it can be observed that the activity concentrations of  $^{238}\text{U}$  ranged from  $23 \pm 2$  to  $30 \pm 3$   $\text{Bq kg}^{-1}$ ,  $^{232}\text{Th}$  varied from  $48 \pm 4$  to  $76 \pm 6$   $\text{Bq kg}^{-1}$  and  $^{40}\text{K}$  from  $438 \pm 56$  to  $820 \pm 103$   $\text{Bq kg}^{-1}$ . Sample S3L4 has the highest activities for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ . The lowest values were obtained from different layers, Sample S3L3 ( $23 \pm 2$   $\text{Bq kg}^{-1}$ ) for  $^{238}\text{U}$ , Sample S3L1 has the lowest activity for  $^{232}\text{Th}$  ( $48 \pm 4$   $\text{Bq kg}^{-1}$ ) and  $^{40}\text{K}$  ( $430 \pm 56$   $\text{Bq kg}^{-1}$ ).

The average activity concentration for  $^{238}\text{U}$  reported in the continental crust is 36  $\text{Bq kg}^{-1}$  and in soil is 22  $\text{Bq kg}^{-1}$ ; for  $^{232}\text{Th}$ , in the continental crust is 44  $\text{Bq kg}^{-1}$  and in soil is 37  $\text{Bq kg}^{-1}$  and  $^{40}\text{K}$ , in the continental crust is 850  $\text{Bq kg}^{-1}$  and in soil 400  $\text{Bq kg}^{-1}$ <sup>(31)</sup>. At Site A borehole, the activity for  $^{238}\text{U}$  is close to that report by Eisenbud *et al.*<sup>(31)</sup>, whereas the lowest value for  $^{232}\text{Th}$  is 48  $\text{Bq kg}^{-1}$  and the highest value exceeds 76  $\text{Bq kg}^{-1}$  In the case of  $^{40}\text{K}$ , it is 820  $\text{Bq kg}^{-1}$ .

**Table 3. The activity concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  ( $\text{Bq kg}^{-1}$ ) and Th/U ratio in Site A borehole.**

Sample ID	$^{238}\text{U}$	$^{232}\text{Th}$	$^{40}\text{K}$	Th/U ratio
S3L1	$25 \pm 2$	$48 \pm 4$	$438 \pm 56$	5.78
S3L2	$23 \pm 2$	$66 \pm 5$	$498 \pm 63$	8.73
S3L3	$23 \pm 2$	$67 \pm 5$	$473 \pm 56$	9.02
S3L4	$30 \pm 3$	$76 \pm 6$	$820 \pm 103$	7.56
S3L5	$28 \pm 3$	$52 \pm 4$	$698 \pm 88$	5.77
S3L6	$28 \pm 3$	$68 \pm 5$	$513 \pm 66$	7.41
Mean	$26 \pm 3$	$63 \pm 5$	$573 \pm 72$	

**Activity concentrations of  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and  $^{40}\text{K}$  in Site B borehole S4L1–S4L5 in Lugbe**

The Th/U ratio ranged from 6.12 to 8.86 as shown in Table 4. The highest Th/U ratio of 8.86 is obtained from Sample S4L5 and the lowest Th/U ratio from Sample S4L1 is 6.12. Th/U given by ref. (31) for the continental crust is 1.2 and for granite is 1.8. The Th/U ratio is 7 and 4 times higher than the average value for the continental crust and granite, respectively. For example, in Hornfel from the Death Bend area, Th/U is 3 and the Th/U ratio in rocks in the environs of Swieradow Zdroj varies between 1.5 and 3.2<sup>(32)</sup>.

In Table 4, the measured activity concentrations of  $^{40}\text{K}$ , nuclides from  $^{232}\text{Th}$  series ( $^{208}\text{Tl}$ ,  $^{228}\text{Ac}$ ) and  $^{238}\text{U}$  series ( $^{214}\text{Pb}$ ,  $^{214}\text{Bi}$ ) in the investigated rock samples are presented. It is noted that the activity concentrations of  $^{238}\text{U}$  varied from  $16 \pm 12$  to  $223 \pm 2$  Bq  $\text{kg}^{-1}$ ,  $^{232}\text{Th}$  from  $43 \pm 4$  to  $49 \pm 4$  Bq  $\text{kg}^{-1}$  and  $^{40}\text{K}$  from  $817 \pm 103$  to  $1011 \pm 128$  Bq  $\text{kg}^{-1}$ .

At Site B borehole, Sample S4L1 has the highest activity for  $^{238}\text{U}$  and  $^{40}\text{K}$  and Sample S4L4 has the high activity for  $^{232}\text{Th}$ . The lowest values were obtained in Sample S4L5:  $16 \pm 2$  Bq  $\text{kg}^{-1}$  for  $^{238}\text{U}$  and  $817 \pm 103$  Bq  $\text{kg}^{-1}$  for  $^{40}\text{K}$ . Sample S4L2 has  $44 \pm 4$  Bq  $\text{kg}^{-1}$  for  $^{232}\text{Th}$ .

The average activity concentration for  $^{238}\text{U}$  reported in the continental crust is 36 Bq  $\text{kg}^{-1}$  and in

soil is 22 Bq  $\text{kg}^{-1}$ ; for  $^{232}\text{Th}$ , in the continental crust is 44 Bq  $\text{kg}^{-1}$  and in soil is 37 Bq  $\text{kg}^{-1}$  and for  $^{40}\text{K}$ , in the continental crust is 850 Bq  $\text{kg}^{-1}$  and in soil 400 Bq  $\text{kg}^{-1}$ <sup>(31)</sup>.

Compared with Site B borehole, the activity concentrations of  $^{238}\text{U}$  and  $^{232}\text{Th}$  are within the range but for  $^{40}\text{K}$ , it is 1.2 times higher.

**Comparison of activity concentrations of  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and  $^{40}\text{K}$  at Site A borehole, Gosa and Site B borehole, Lugbe**

The findings of the study showed that at Site A borehole, Sample S3L4 has the highest activity for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ , whereas at Site B borehole, Sample S4L1 has the highest activity for  $^{238}\text{U}$  and  $^{40}\text{K}$  and Sample S4L4 has the highest activity for  $^{232}\text{Th}$ .

Such same homogeneity of activity concentration reporting higher in Sample S3L4 from the structural/tectonic point of view could be that the area underwent complex polyphase deformation shown by the tectonometamorphic phase that is caused by granitic intrusions. At Site B borehole, such variation in the activity concentration in different layers may be due to the oxidation condition of  $^{238}\text{U}$  and the colloidal sediment containing carbonate and bicarbonate constituent that keep the  $^{238}\text{U}$  and  $^{40}\text{K}$  mobile. The area requires further geochemical investigation.

The lowest activity concentration of  $^{232}\text{Th}$  and  $^{40}\text{K}$  at Site A borehole was obtained from Sample S3L1, whereas the lowest value for  $^{238}\text{U}$  was from Sample S3L3. The layer Sample S3L1 may have been affected by the same geological attribute associated with  $^{232}\text{Th}$  and  $^{40}\text{K}$  mineral composition during Pan-African Orogeny event. In comparison, it is noted that at Site B borehole the lowest activity concentrations of  $^{238}\text{U}$  and  $^{40}\text{K}$  was from Samples S4L5 and S4L2 has the lowest activity of  $^{232}\text{Th}$ . It may be the low distribution

**Table 4. The activity concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in (Bq  $\text{kg}^{-1}$ ) and Th/U ratio in Site B borehole.**

Sample	$^{238}\text{U}$	$^{232}\text{Th}$	$^{40}\text{K}$	Th/U ratio
S4L1	$23 \pm 2$	$46 \pm 4$	$1011 \pm 128$	6.12
S4L2	$18 \pm 2$	$44 \pm 4$	$970 \pm 122$	7.36
S4L3	$22 \pm 2$	$49 \pm 4$	$907 \pm 116$	6.87
S4L4	$22 \pm 2$	$50 \pm 4$	$870 \pm 110$	6.90
S4L5	$16 \pm 2$	$47 \pm 4$	$817 \pm 103$	8.86
Mean	$20 \pm 2$	$47 \pm 4$	$915 \pm 116$	

**Table 5. Summary of activity concentration of radioisotopes in soil samples in Gosa and Lugbe Abuja and other parts of the world<sup>(24)</sup>.**

Region/country	$^{232}\text{Th}$ (Bq $\text{kg}^{-1}$ )		$^{238}\text{U}$ (Bq $\text{kg}^{-1}$ )		$^{40}\text{K}$ (Bq $\text{kg}^{-1}$ )	
	Range	Mean	Range	Mean	Range	Mean
Gosa, Abuja, north central Nigeria <sup>a</sup>	48–76	63	23–30	26	438–820	573
Lugbe, Abuja, north central, Nigeria <sup>a</sup>	44–50	47	16–23	20	817–1011	915
Ikogosi-Ekiti, south western Nigeria <sup>b</sup>	1–108	82	4–111	58	40–2437	1203
Malaysia <sup>c</sup>	63–110	82	49–86	66	170–430	310
World <sup>d</sup>	7–50	45	16–116	33	100–700	420

<sup>a</sup>Present study.<sup>b</sup>Ref.(34).<sup>c</sup>Ref.(33).<sup>d</sup>Ref.(2).



of acidic felsic intrusions in the subsurface sediment. The region requires further activity concentration of radionuclides in other locations and soil geochemical research.

At Site A borehole, Sample S3L3 has the highest Th/U ratio of 9.02 and Sample S4L5 at Site B borehole with a value of 8.86. These two layers indicate whether enrichment or relative depletion of radioisotopes may have occurred (Tables 3 and 4). The lowest Th/U ratio at Site A borehole is noted in Sample S3L5, whereas at Site B borehole, in Sample S4L1.

Moreover, a comparison of the activity concentrations of uranium, thorium and potassium in the present study with previous studies is presented in Table 5. Most of the reports were not from the sequential subsurface layers as this present study shows, but they are all from soils and rocks. The results in the present work show good agreement with those reported in previous studies. In general, all results existed within the range given in ref. (33).

## CONCLUSION

The results of gamma-ray measurements presented in this paper give current information about the natural radioactivity variation in the layers of varying depths. The variation of activity concentrations of radionuclides with depth is a function of lithological and tectonic factors.

The activity concentrations at Site A borehole has a mean value of  $26 \pm 3$ ,  $63 \pm 5$ ,  $573 \pm 72$  Bq kg<sup>-1</sup> for <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K, respectively. The activity concentrations at Site B borehole have a mean value of  $20 \pm 2$  for <sup>238</sup>U,  $46 \pm 4$  for <sup>232</sup>Th and <sup>40</sup>K has a mean value of  $915 \pm 116$  Bq kg<sup>-1</sup>. The higher activity concentrations of <sup>232</sup>Th and <sup>238</sup>U are found in Site A at Gosa and Site B has a lower radioactivity and it is suggested that both sites require further research on the activity concentration in groundwater and geochemical investigations.

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ACTIVITY CONCENTRATION OF  $^{238}\text{U}$ ,  $^{232}\text{Th}$  AND  $^{40}\text{K}$

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