Natural Radioactivity and Geological Influence on Subsurface Layers at Kubwa and Gosa Area of Abuja, Northcentral Nigeria

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Natural radioactivity and geological influence on subsurface layers at Kubwa and Gosa area of Abuja, Northcentral Nigeria

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Abstract The concentration of ^{238}U, ^{232}Th and ^{40}K in rock samples were analysed using gamma ray spectrometry. In Kubwa, the concentration ranges from 15 to 52 Bq kg^{-1} for ^{238}U, 32 to 84 Bq kg^{-1} for ^{232}Th and 119 to 705 for ^{40}K Bq kg^{-1}. In Gosa area, the concentration of ^{238}U ranges from 23 to 30 Bq kg^{-1}, ^{232}Th varied from 48 to 76 Bq kg^{-1}, and ^{40}K varied from 438 to 820 Bq kg^{-1}. The dose rate, radium equivalent activity and annual effective dose rate at Kubwa and Gosa were calculated and compared with international standard values.

Keywords Abuja Boreholes · Geology · Radionuclides · Radiation hazards

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Introduction

Uranium (U), thorium (Th) and potassium (K) are the major radionuclides contained in the Earth's crust [1]. Since the age of the earth is approximately the age of ^{238}U, other radionuclides from the ^{238}U-series are also found in the crust [2]. The average crystal abundance of uranium and thorium are 2.8 ppm (parts per million) and 10 ppm and the typical ranges are 1.5–6.5 and 6–20 ppm, respectively [3, 4]. The average Th/U ratio in most rocks, in which uranium is not enriched, is 3.5–1 [4].

Uranium and thorium are incorporated into late crystalline magmas and residual solutions due to their large ionic radii, which prevent them from existing in crystalline silicate. Therefore, uranium and thorium are mainly found in granites and pegmatites [1]. Rock types are classified into different groups according to how they are formed. There are three main groups: igneous, metamorphic and sedimentary rocks. Igneous rocks are formed from magma, metamorphic rocks are re-crystallized rocks and sedimentary rocks are rocks that have been formed by interpose or harden in the water or in dry land. The primary mechanism by which the bedrock was formed includes sedimentation and melting of the mantle and the crust. Higher activity concentrations of radionuclides are found mostly in igneous rocks that comprise intrusive materials [2].

The specific levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area, and to the content in ^{238}U, ^{232}Th and ^{40}K of the rock from which soils originate in each area [5–8].

Naturally occurring uranium contains 99.2745 % by weight ^{238}U, 0.7200 % ^{235}U, and 0.0055 % ^{234}U [9]. In the United States, the activity concentration of ^{222}Rn, ^{226}Ra and uranium in groundwater has been extensively studied.

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There, high concentrations are also attributed to uranium minerals in granite and uranium minerals in pegmatite associated with metamorphic rocks [10, 11].

The activity concentrations of natural radionuclides in groundwater are connected to the activity concentrations of uranium (^{238}U and ^{235}U) and thorium (^{232}Th) and their decay products in soil and bedrock [12]. The study on environmental radiation protection and determination of contamination of natural radionuclides such as uranium, thorium and potassium in soil and crops samples are very important as part of environmental health surveillance programs in the environmental sciences [13].

Extensive work has been carried out in many countries to evaluate the risks associated with naturally occurring radionuclide materials, NORM [5, 14]. In Nigeria, NORM levels have been studied in surface soils in Ijero-Ekiti [15], in soil and water around cement Company in Ewekoro [16] and in rocks found in Ekiti and Ondo State [17]. Only insignificant levels of NORM were identified [15].

Regarding the previous studies as stated above, the reasons for evaluating the radionuclides in subsurface rocks of Kubwa and Gosa areas are listed below:

(1) The World Health Organization (WHO) and UNICEF report for 2012 [18] ranked Nigeria as one of the most populous country without adequate water and proper sanitation.
(2) The Abuja Water Board has a designed capacity which is in anti-phase with the city growth in the recent. The increase in demand for water has led to compulsory alternative source of borehole (groundwater) to augment the inadequate public water supply [19].
(3) Borehole is the only source of water in Kubwa and Gosa of densely populated area of about 0.6–1 million inhabitants.
(4) The risk associated with NORM in water–rock interactions needs urgent attention to restrict the inhabitants to the exposure of the water that comes from unsafe and radionuclide rich aquifer bearing rock formation.
(5) However, to evaluate the suitability of different borehole locations for obtaining groundwater for consumption and to educate the inhabitants of the satellite towns and suburbs' the potential problems associated radioactive elements in water–rock interaction.

Geology and hydrogeology of the study area

The area of study forms part of the Basement Complex of Northcentral Nigeria; with lithologic units falling under three main categories, which include (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 Paleozoic age, also known as Pan-African Granites. All these rocks have been affected and deformed by the Pan-African thermotectonic event. Detailed reports of the lithological description, age, history, structure and geochemistry of the Basement Complex of Nigeria [20–22]. The study areas are bounded by latitudes 8°53′N–9°13′N and longitudes 7°00′E–7°30′E. The sites of the boreholes in the area are in the coordinates latitude 9°6′16.7″N and longitude 7°16′26.0″E, Kubwa and (latitude 8°56′45.6″N and longitude 7°13′26.2″E, Gosa borehole points. Figure 1 shows the geology and mineral map of the area.

Geophysical investigation was conducted to locate the suitable sites for drilling, also structures that control the aquifer and depth to the basement terrain groundwater. Two soundings were made in and around the study areas to choose the dense populated zone using vertical electrical sounding (VES) [19]. The Schlumberger configuration in VES with 5 m spacing was used to obtain field data. VES probes the vertical variation in resistivity of the subsurface, thereby indicating the presence of fluid and ionic concentration in the subsurface materials. It is also applied to determine the depth to bedrock, delineate the various units that constitute the overburden (regolith), determine the degree of fracturing of the bedrock; all of which would help in making the choice for a feasible site for constructing a successful borehole [19]. Hydrogeologically motivated boreholes in Kubwa and Gosa with geophysical log data were drilled. The lithological units obtained during the drilling are shown in Tables 1 and 2 below. Figures 2 and 3 show the well log of the two borehole sites in Kubwa and Gosa.

Materials and methods for gamma-spectroscopy

Sampling and sample preparation

A total of fifteen samples, nine samples from borehole layers at Kubwa (to a depth of 60 m) and six samples from borehole layers at Gosa (to a depth of 50 m) collected during drilling of boreholes by cutting method of technical procedure [23] were dried at 105 °C each overnight, crushed and pass through 250 µm Sieve mesh. The fine powdered samples were homogenized, 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 [19, 24, 25].

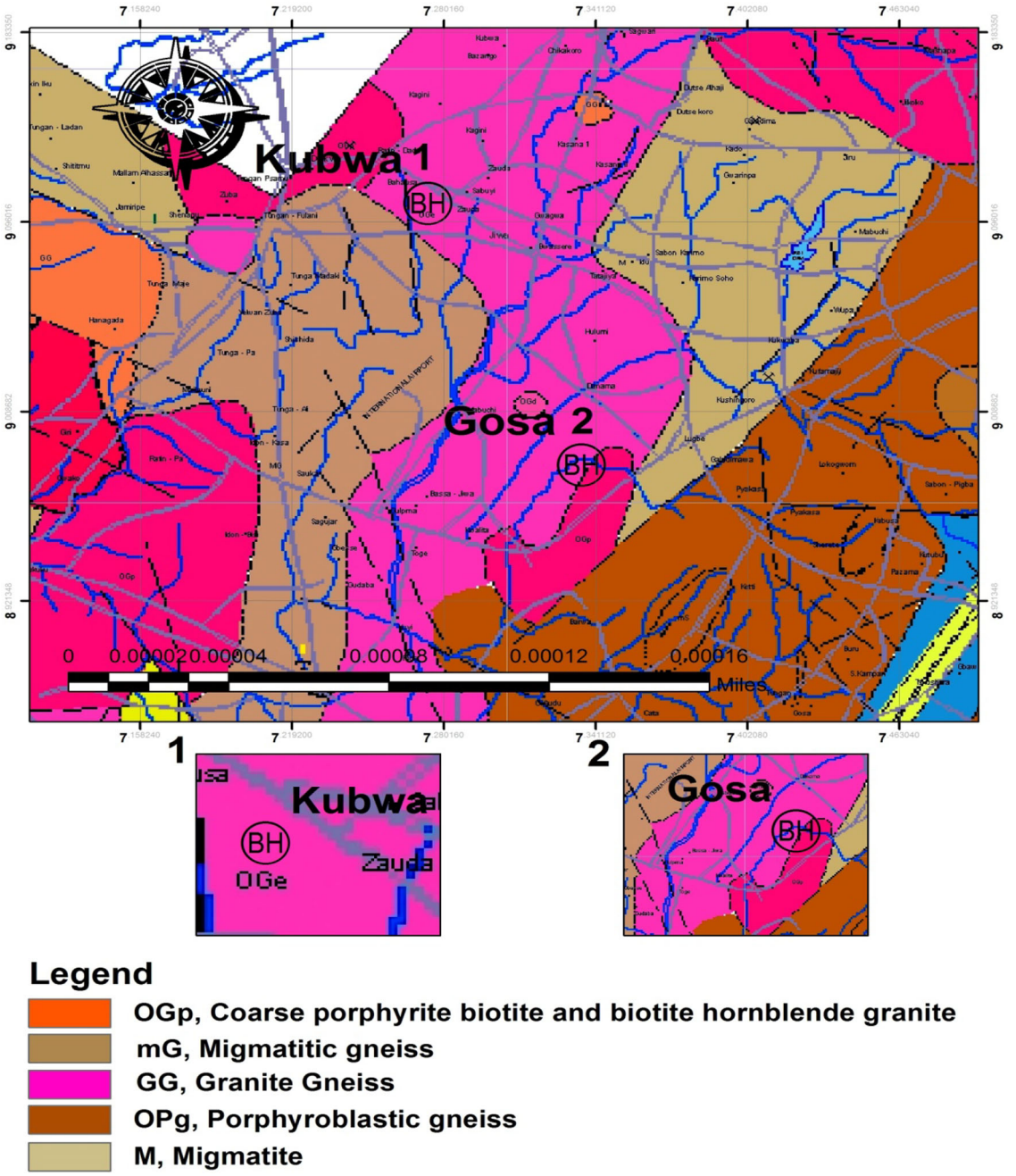

Fig. 1 Geology and mineral map of the study area

Experimental method for γ- spectroscopy

Experiments were carried out using the gamma ray spectroscopy facilities at the Nuclear Lab. 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}Co. The detector used in these measurements was a Canberra GC2018 with Genie-2000 software. The detector was cooled by liquid nitrogen and pre-amplifier were placed inside a lead shield to reduce background radiation [19]. Under the conditions of secular equilibrium, ^{232}Th concentration was determined from the ^{208}Tl using the 583 keV peak and ^{228}Ac by using the 911 keV peak. ^{238}U was determined from the average concentrations of the ^{214}Pb by using the 352 keV peak and ^{214}Bi by using the 609 keV peak [26]. The 1,460 keV peak was used to

Table 1 Depth and lithologic unit of Kubwa borehole. The drilling point coordinates (Lat. 9°6′16.7″N and Long. 7°16′26.0″E, GPS-model: extrex high sensitivity 2000–2007 Garmin Ltd) (60 m)

Sample ID	Depth (m)	Thickness (m)	Lithology description
S2L1	0–7.0	7.0	Brownish ash sandy clay gravely interbedded
S2L2	7.0–13.4	6.4	Clay with bright red
S2L3	13.4–21.0	7.6	Sandy clay micaceous, brownish with feldspar
S2L4	21.0–29.0	8.0	Fin to coarse sandy clayey and gravel smoky
S2L5	29.0–36.4	7.4	Clay sandy, fine grain size, darkish ash feldspar
S2L6	36.4–43.0	6.6	Silty clay, interbedded, bright ash to glacy feldspar
S2L7	43.0–44.0	1.0	Fine to coarse ashy sandy clay
S2L8	44.0–51.0	7.0	Fine to coarse sand, greyish
S2L9	51.0–61.1	10.1	Micaceous-gravely sandy, fine-medium coarse darkish to grey

Table 2 Depth and lithologic unit of Gosa borehole. 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

Sample ID	Depth (m)	Thickness (m)	Lithology description
S3L1	0–4.0	4.0	Sandy clay, reddish brown laterite top soil
S3L2	4.0–10.0	6.0	Sandy clay, fine to medium, reddish to yellow
S3L3	10.0–11.3	1.3	Clay sandy feldspar yellowish brown pebbly
S3L4	11.3–18.5	7.2	Micaceous clayey, grey to black
S3L5	18.5–24.0	5.5	Sandy shinny greyish to black feldspar
S3L6	24.0–33.0	9.0	Fine medium shinny, quartz, interbedded, greyish ash feldspar

determine the concentration of ^{40}K. Each sample was put into a shielded HPGe detector and measured for 21,600 s and the background gamma-ray spectrum of the detection system was determined with an empty Marinelli beaker under identical conditions, and was subtracted from the spectra of each sample.

The specific activity was determined by comparison with the International Atomic Energy Agency, IAEA standard samples S-14 (Thorium ore) and SL-2 (Lake Sediment). The International Atomic Energy Agency, IAEA standard samples S-14 and SL-2 were used as reference materials and were mixed with SiO_2 in Marinelli

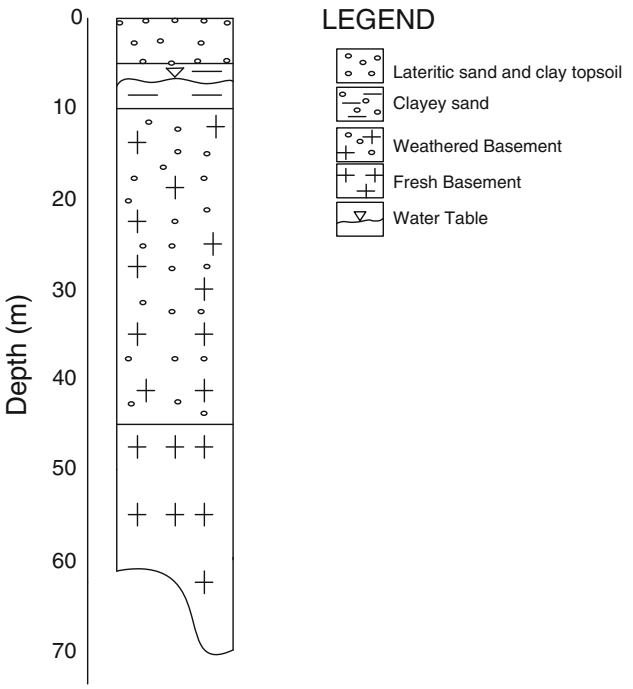

Fig. 2 Lithologic log of representative borehole drilled around Kubwa areas, 60 m, (Lat 9°6′16.7″ and Long: 7°16′26.0″E)

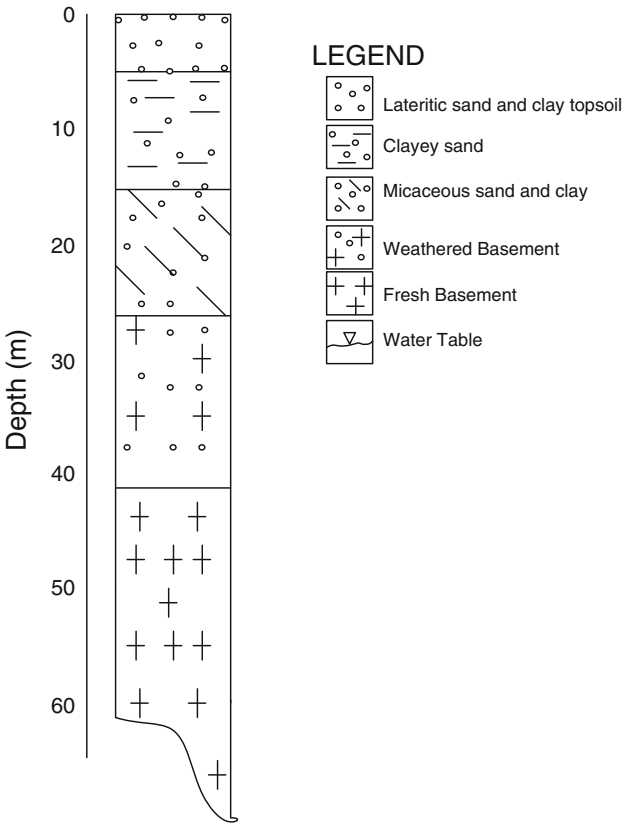

Fig. 3 Lithologic log of representative borehole drilled around Gosa areas, 50 m, (Lat: 8° 56′45.6″ and Long: 7°13′26.2″ E)

Table 3 The concentrations of uranium, thorium (ppm) and ^{40}K(%) at sites Kubwa (S2L1–S2L9) and Gosa (S3L1–S3L6) boreholes

No.	Sample ID	Weight (g)	Concentration (ppm)		%	Th/U
			Uranium	Thorium	^{40}K	Ratio
1	S2L1	503.35	4.2 ± 0.4	20.8 ± 2.0	0.4 ± 0.1	4.95
2	S2L2	520.20	1.9 ± 0.1	7.8 ± 1.0	1.3 ± 0.2	4.22
3	S2L3	512.75	2.6 ± 0.3	14.2 ± 1.0	1.9 ± 0.3	5.37
4	S2L4	584.48	3.2 ± 0.3	9.1 ± 1.0	2.0 ± 0.3	2.89
5	S2L5	529.82	1.2 ± 0.1	10.0 ± 1.0	1.6 ± 0.2	8.36
6	S2L6	544.02	2.8 ± 0.3	17.1 ± 1.0	2.3 ± 0.3	6.14
7	S2L7	503.22	3.5 ± 0.3	19.1 ± 2.0	2.2 ± 0.3	5.52
8	S2L8	593.36	3.3 ± 0.3	19.1 ± 2.0	2.4 ± 0.3	5.86
9	S2L9	564.26	2.5 ± 0.2	17.2 ± 1.0	2.4 ± 0.3	6.83
10	S3L1	478.46	2.1 ± 0.2	11.8 ± 1.0	1.4 ± 0.2	5.78
11	S3L2	433.89	1.9 ± 0.2	16.2 ± 1.0	1.6 ± 0.2	8.73
12	S3L3	427.89	1.8 ± 0.2	16.5 ± 1.0	1.5 ± 0.2	9.02
13	S3L4	488.40	2.5 ± 0.2	18.6 ± 2.0	2.6 ± 0.3	7.56
14	S3L5	569.29	2.2 ± 0.2	12.9 ± 1.0	2.2 ± 0.3	5.77
15	S3L6	593.55	2.3 ± 0.2	16.7 ± 1.0	1.6 ± 0.2	7.41

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 SiO_2 in a Marinelli beaker. Another Marinelli beaker contains only 100 g of SiO_2 was to provide 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 Bq kg^{-1}. A weight of 74.18 g of SL-2 was mixed with 100 g of SiO_2 in a Marinelli beaker.

Results and discussion

Concentration of ^{232}Th, ^{238}U and ^{40}K at Kubwa borehole S2L1-S2L9

The measured concentrations of ^{40}K, nuclides from ^{232}Th series (^{208}Tl, ^{228}Ac) and ^{238}U series (^{214}Pb, ^{214}Bi) in investigated rock samples are presented. ^{238}U concentrations were calculated as the arithmetic means of the activities of ^{214}Pb and ^{214}Bi isotopes and ^{232}Th as ^{208}Tl and ^{228}Ac respectively. In the Table 3, concentrations of ^{40}K(%), thorium and uranium (ppm) in measured samples calculated using conversion factors (^{238}U; 1 ppm = 12.35 Bq kg^{-1}, ^{232}Th; 1 ppm = 4.06 Bq kg^{-1}) whereas 1 % of ^{40}K = 313 Bq kg^{-1} [27] to obtain the values plotted for the activity concentrations against Sample ID in Fig. 4. For all rocks Th/U ratio was calculated as shown in Table 3.

Table 3 shows the concentrations of uranium and thorium (ppm) and ^{40}K (%). As shown in Fig. 4, the highest value of ^{40}K refers to the sample layer, S2L9 (750 ± 94 Bq kg^{-1}), it may be due to felspatic and felsic sediments of chemical weathering and complexation of organic constituents in aqueous phase close to aquifer bearing formation. The range varies from 119 ± 15 to 750 ± 94 Bq kg^{-1} in the borehole layers. Distinctly low value was noted in S2L1, about 119 ± 15 Bq kg^{-1}. In Fig. 3, it shows that the higher concentration of ^{228}Ac (^{232}Th) refers to S2L1, with a value of 84 ± 7 Bq kg^{-1}, the region covers with porphyriblastic gnesses and granitic gneiss from the geologic map, Fig. 1. In sample collected from layer S2L2, it has a value of 32 ± 3 Bq kg^{-1}, and distinctly lower. It means that the layer may have experienced structural deformation that fractionized the sediments of ^{232}Th and drive to a short distance to the neighbouring layer, S2L1 in aqueous phase. It was observed that S2L7 and S2L8 concentrations of ^{232}Th are close, 78 ± 6 and 77 ± 6 Bq kg^{-1}. The layers are inferred to be porphyroblastic gneisses and biotite hornblende granodiorite. Those two layers may be due to metamorphism processes intercalate each other but different physical properties in terms of grain size, colour and structure and reflect the same radioactivity measurements. Concentration of ^{232}Th in the investigated rocks varies in the range from 32 ± 3 to 84 ± 7 Bq kg^{-1}. Noted concentrations are compared with average concentrations of ^{232}Th in the continental crust [28]. The measured value of ^{228}Ac (^{232}Th) concentration in S2L1 exceeds the average concentration refers to the continental crust almost twice [19].

The highest value refers to the sample collected from S2L1, (52 ± 5 Bq kg^{-1}), the same geological effect of porphyroblastic gneisses and granitic gneiss constituted such activity level, refers to Fig. 1. Distinctly lower value

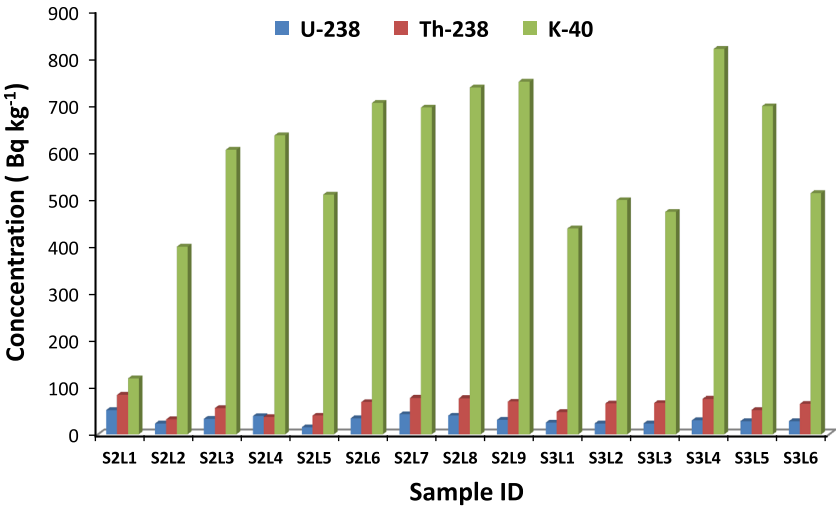

Fig. 4 Concentration of ^{238}U, ^{232}Th and ^{40}K on Sample ID, S2L1-S2L9, (Kubwa), S3L1-S3L6, Gosa, Abuja

Table 4 Comparing the lithologic rock type and the concentration of ^{238}U, ^{232}Th and ^{40}K (Bq kg^{-1}) in Kubwa (S2L1–S2L9) and Gosa (S3L1–S3L6) boreholes

Sample ID	Lithology	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
S2L1	Brownish ash sandy clay gravely interbedded	52 ± 5	84 ± 5	119 ± 15
S2L2	Clay with bright red	23 ± 2	32 ± 2	399 ± 51
S2L3	Sandy clay micaceous, brownish with feldspar	33 ± 3	56 ± 5	605 ± 77
S2L4	Fin to coarse sandy clayey and gravel smoky	39 ± 4	37 ± 3	636 ± 81
S2L5	Clay sandy, fine grain size, darkish ash feldspar	15 ± 1	40 ± 3	510 ± 64
S2L6	Silty clay, interbedded, bright ash to glacy feldspar	34 ± 3	69 ± 5	705 ± 89
S2L7	Fine to coarse ashy sandy clay	43 ± 4	78 ± 6	695 ± 88
S2L8	Fine to coarse sand, greyish	40 ± 4	77 ± 6	738 ± 93
S2L9	Micaceous-gravely sandy, fine-medium coarse darkish to grey	31 ± 3	70 ± 6	750 ± 94
S3L1	Sandy clay, reddish brown laterite top soil	25 ± 2	48 ± 4	438 ± 56
S3L2	Sandy clay, fine to medium, reddish to yellow	23 ± 2	66 ± 5	498 ± 63
S3L3	Clay sandy feldspar Yellowish brown pebbly	23 ± 2	67 ± 5	473 ± 56
S3L4	Micaceous clayey, grey to black	30 ± 3	76 ± 6	820 ± 103
S3L5	Sandy shinny greyish to black feldspar	28 ± 3	52 ± 4	698 ± 88
S3L6	Fine medium shinny, quartz interbedded, greyish ash feldspar	28 ± 3	65 ± 5	513 ± 66

was obtained from S2L5, (15 ± 1 Bq kg^{-1}). Concentration of ^{238}U in investigated rocks calculated with assumption of radioactivity equilibrium in uranium series varies in the range from 15 ± 1 (S2L5) to 52 ± 5 Bq kg^{-1} (S2L1). The average concentrations of ^{238}U are higher except in samples S2L2, S2L3, S2L5 and S2L9 respectively. Figure 4 shows the plot of concentrations of ^{238}U, ^{232}Th and ^{40}K of rock samples collected in Kubwa and Gosa Borehole of the study area.

Table 3 shows the Th/U ratio in Kubwa varies in the range from 2.89 to 8.36. The highest value refers to the fifth layer, S2L5, whereas the lowest value was noted in the sample collected from the fourth layer, S2L4. Obtained Th/U ratios are higher than data published in literature concerning rocks of Karkonosze-Irera block equals 3 [29] and also found that the Th/U ratio in rocks in the environs of Swieradow Zdroj varies between 1.5 and 3.2 are higher than the Th/U ratio [28], for the continental crust equals 1.2 and for granite is 1.8, respectively. In cited literature [30], the values are distinctly lower than Th/U ratio obtained for investigated rock samples from Kubwa Borehole.

Comparing the lithological units and the concentrations of ^{238}U, ^{232}Th and ^{40}K in the Kubwa area, as shown in Table 4, it is noted that brownish ash sandy clay, gravely interbedded constituted the highest activity value which is inferred to be porphyroblastic gneisses and biotite hornblende granodiorite geologically for ^{238}U and ^{232}Th, S2L1, whereas Micaceous-gravely sandy, fine-medium coarse

darkish to grey reported higher activity of ^{40}K, S2L9, which could be felsinc sediments of migmatite gneiss.

Concentration of ^{232}Th, ^{238}U and ^{40}K at Gosa borehole, (S3L1-S3L6)

The measured concentrations of ^{40}K, nuclides from ^{232}Th series (^{208}Tl, ^{228}Ac) and ^{238}U series (^{214}Pb, ^{214}Bi) in investigated rock samples are presented. ^{238}U concentrations were calculated as the arithmetic means of the activities of ^{214}Pb and ^{214}Bi isotopes. In Table 3, concentrations of ^{40}K(%), thorium and uranium (ppm) in measured samples were calculated using conversion factors [27] and presented in Fig. 3.

Table 3 shows the Th/U ratio in Gosa ranged from 5.77 to 9.02. Sample S3L3 has the highest Th/U ratio of 9.02 and Sample S3L7 has the lowest Th/U ratio of 5.77. Th/U [28], for the continental crust equals 1.2 and for granite is 1.8. At Gosa borehole, the Th/U ratio is seven and five times higher than the continental crust and granite respectively. For example, in hornfel from Death Bend area, Th/U equals 3 and Th/U ratio in rocks in the environs of Swieradow Zdroj varies between 1.5 and 3.2 [29].

In Fig. 4, it can be observed that the concentration of ^{238}U ranged from 23 ± 2 to 30 ± 3 Bq kg^{-1}, ^{232}Th varied from 48 ± 4 to 76 ± 6 Bq kg$^{-1,}$ and ^{40}K varied from 438 ± 56 to 820 ± 103 Bq kg^{-1}. Sample S3L4 has the highest concentrations for ^{238}U, ^{232}Th and ^{40}K, the geological formation in the region is inferred as the same in Kubwa, coarse porphyroblastic gneisses and biotite hornblende granodiorite. It could be attributed to metasediment and metamorphism process of tectonic event in Pan-African granite. The lowest values were obtained from different layers, Sample S3L3 (23 ± 2 Bq kg^{-1}) for ^{238}U, Sample S3L1 has the lowest concentration for ^{232}Th (48 ± 4 Bq kg^{-1}) and ^{40}K (438 ± 56 Bq kg^{-1}).

The average concentration for ^{238}U reported in continental crust is 36 Bq kg^{-1} and for soil is 22 Bq kg^{-1}, for ^{232}Th, continental crust is 44 Bq kg^{-1} and for soil is 37 Bq kg^{-1} for ^{232}Th and ^{40}K, continental crust is 850 Bq kg^{-1} and for soil 400 Bq kg^{-1}]. At Kubwa borehole, the concentration for ^{238}U is close to the report [28], whereas the lowest value for ^{232}Th is 48 Bq kg^{-1} and the highest value exceeds 76 Bq kg^{-1}. In the case of ^{40}K, it is 820 Bq kg^{-1}.

Comparing the lithological units and the concentrations of ^{238}U, ^{232}Th and ^{40}K in the Gosa area as shown in Table 4, it is noted that Micaceous clayey, grey to black constituted the highest concentration value which is inferred to be porphyroblastic gneisses and biotite hornblende granodiorite geologically for ^{238}U, ^{232}Th and ^{40}K in the same layer, S3L4.

Comparison of concentrations of ^{232}Th, ^{238}U and ^{40}K at Kubwa borehole and Gosa borehole

(1) The findings of the study showed that at Kubwa borehole, the sample S2L1 reported the highest concentration of ^{238}U and ^{232}Th whereas Sample S3L4 in Gosa has the highest concentration for ^{238}U, ^{232}Th and ^{40}K. Such same homogeneity of concentration reporting higher in sample S2L1 and S3L4 from the structural/tectonic point of view could be the assemblage of sediments of porphyroblastic gneisses and biotite hornblende granodiorite in varying concentrations caused by granitic intrusions.

(2) The lithological units that constituted higher in S2L1 is brownish ash sandy clay, gravely interbedded for only ^{238}U and ^{232}Th whereas S3L4 reported high concentration of ^{238}U, ^{232}Th and ^{40}K in a single layer with lithologic unit made of Micaceous clayey, grey to black. In that case, it could be that the interbedding of micaceous sand stone constituted the activity of ^{40}K.

However, a comparison of the concentrations of ^{238}U, ^{232}Th and ^{40}K in the present study with previous studies are presented in Table 4. Most of the reports were not from sequential subsurface layers as the present study, but they are all soils and rocks. The results in present work shows a good agreement with those reported in previous studies. In general, all results existed within the range [30].

Comparison of concentrations of ^{232}Th, ^{238}U and ^{40}K in the upper layer (0–6 m) below the ground level in the study area (Kubwa and Gosa)

The objective of this comparison was to detect the area that reports higher activity concentrations of ^{238}U, ^{232}Th and ^{40}K in order to recommend for environmental assessment of radiological impact on inhabitants in the region. In Table 4 which comprises S2L1 (Kubwa upper layer) and S3L1 (Gosa upper layer) indicate that the natural radionuclides are not uniformly distributed, thus, the knowledge of the natural radioactivity on in the study area is important for their management and the possible radiation exposure to the population. This knowledge is essential for the development of guide report for environmental assessment recommendation if found higher than permissible limit. The goal of evaluating the upper layer is to determine the air absorbed dose rate, Dc, radium equivalent (Ra_{eq}), the external hazard index (H_{ex}) and the annual effective dose rate (AEDR), thus, to determine the environmental exposure of the people within the study area.

Table 5 Calculated dose rate, radium equivalent activity, external radiation hazard and annual effective dose rate compared with other studies

Location	Dc (nGy h^{-1})	Ra_{eq} (Bq kg^{-1})	Hex	AEDR (μ Sv year^{-1})	Reference
Kubwa, Abuja Northcentral Nigeria	80	180	0.49	98	Current study
Gosa, Abuja Northcentral Nigeria	59	124	0.34	72	Current study
Port Harcourt, Nigeria	46	92	0.27	57	[34]
Abeoluta, Ogun State, South Western, Nigeria	84	172	0.48	103	[35]
Izmir, Turkey	86	132	0.52	106	[36]
Kinta District, Malaysia	212	483	1.31	260	[31]
Pontian District, Malaysia	61	136	0.37	238	[37]
World	60	127	0.35	74	[6]

Dose rate

In the study area Eq (1) was used to calculate the external gamma dose rate D_c in air from natural radionuclides for samples from upper layer [5]

$$D_c = 0.462\ A(^{238}U) + 0.604\ A(^{232}Th) + 0.0417\ A(^{40}K), \quad (1)$$

where, D_c is the absorbed dose rate at 1 m from the ground, A(^{238}U), A(^{232}Th) and A(^{40}K) are the concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1} of the samples respectively.

Radium equivalent

Radium equivalent activity was calculated according to the Eq (2) [31].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

Radiation hazard

The gamma ray radiation hazards due to the specified radionuclides were assessed by external radiation hazard and was calculated using Eq (3) [31].

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4,810 \leq 1, \quad (3)$$

where, $A_{Ra\sim}A_U$, A_{Th} and A_K are the average concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. For the radiation hazard to be negligible, it is recommended that the Ra_{eq} activity is lower than the maximum value of 370 Bq kg^{-1}, while the H_{ex} must not exceed the limit of unity.

Annual effective dose rate: The annual effective dose rate (AEDR) in units of μ Sv year^{-1} was calculated by the following formula in Eq. (4).

$$AEDR = D_c(n\,Gy\ h^{-1}) \times 8,760\ h \times 0.2 \times 0.7\ Sv\ Gy^{-1} \times 10^{-3} \quad (4)$$

To estimate the AEDR, the conversion coefficient from absorbed dose rate in air to effective dose (0.7 Sv Gy^{-1}) and outdoor occupancy factor (0.2) [5] was used.

The values obtained from the calculated dose rate, radium equivalent, external radiation hazard and annual effective dose rate of the upper surface samples from Kubwa and Gosa borehole samples are presented in Table 5.

The calculated dose rate was higher at Kubwa with a value of 80 n Gy h^{-1} which is attributed to brownish clay interbedded with gravel as the formation of the surface area. The low dose rate was determined on the sandy clay laterite topsoil with a value of 59 n Gy h^{-1}. The higher radium equivalent activity of 180 Bq kg^{-1} was reported at Kubwa whereas Gosa reported a distinctly lower value of 124 Bq kg^{-1}. The external radiation hazard index of 0.49 was noted at Kubwa and lower value of 0.34 was reported at Gosa. The external hazard index of 0.49 did not exceed the recommended value. All the lower values found at Gosa area may be absence of interconnectivity of fractures reported elsewhere [32]. The AEDR of 98 μSv year^{-1} was noted at Kubwa and lower value was noted at Gosa with a value of 72 μ Sv year^{-1}. The AEDR determined, 98 μ Sv year^{-1} is about 10 % of the recommended value [33], as the maximum permissible effective dose equivalent for member of the public. In Table 5, the values obtained were compared to values reported in other countries [31, 34–37] and the world standard thus, within the range except the reports at Kubwa which was higher than the world standard by a factor of 1.32 or more. The dose rate, radium equivalent and annual effective dose rate at Kubwa borehole reported higher than the world standard [5] by a factor of 1.33, 1.41 and 1.32 respectively.

Comparison of concentrations of ^{232}Th, ^{238}U and ^{40}K in Dei–Dei, Kubwa, Gosa, Lugbe and other Countries

The purpose of this comparison was to compare the values of the results of the present work and the previous work published elsewhere as shown in Table 6. Moreover, a comparison of the concentrations of ^{238}U, ^{232}Th and ^{40}K in the present study with previous studies are presented in Table 6. In general, all results existed within the range [30].

Table 6 Summary of activity concentration of radioisotopes in soil samples in Kubwa and Gosa Abuja and other parts of the world [30]

Region/Country	^{232}Th (Bq kg^{-1})		^{238}U (Bq kg^{-1})		^{40}K (Bq kg^{-1})	
	Range	Mean	Range	Mean	Range	Mean
Kubwa, Abuja, Northcentral Nigeria	32–84	61	15–52	34	236–1,195	573
Gosa, Abuja, Northcentral Nigeria	48–76	63	23–30	26	438–820	573
Ikogosi-Ekiti, South western Nigeria [17]	1–108	82	4–111	58	40–2,437	1,203
Malaysia [30]	63–110	82	49–86	66	170–430	310
China [30]	1–360	41	2–690	84	9–1,800	440
India [30]	14–160	64	7–81	29	38–760	400
Japan [30]	2–88	28	2–59	29	15–990	310
United State [30]	4–130	35	4–140	35	100–700	370
Egypt [30]	2–96	18	6–120	37	29–650	320
Greece [30]	1–190	20	1–240	25	12–1,570	360
Portugal [30]	22–100	51	26–82	49	220–1,230	840
Russia [30]	2–79	30	0–67	19	100–1,400	520
Spain [30]	2–210	33	–	–	25–1,650	570
World [6]	7–50	45	16–116	33	100–700	420

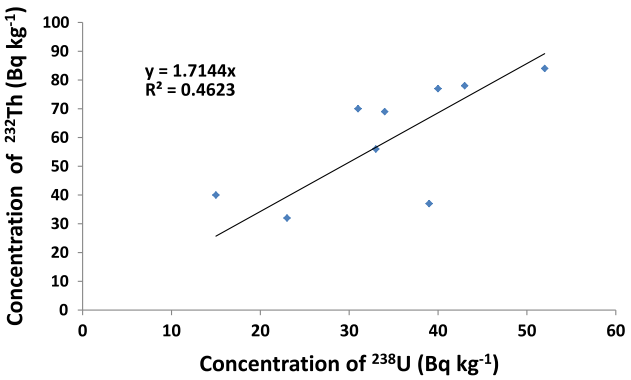

Fig. 5 Correlation between concentration of ^{238}U and ^{232}Th in Kubwa

Correlation between concentrations of ^{232}Th, ^{238}U and ^{40}K in Kubwa and Gosa

In Fig. 5, the correlation coefficient between the concentrations of ^{232}Th and ^{238}U in Kubwa ($R^2 = 0.4623$) indicates poor correlation. No correlation was found between the other radionuclides.

Conclusion

The identified concentrations of ^{232}Th, ^{238}U and ^{40}K in measured rocks have some geological attributes. In Kubwa, the highest concentration reported in S2L1 for ^{238}U and ^{232}Th is attributed to the porphyroblastic gneisses and biotite Hornblende granodiorite intrusions. On the other hand, Gosa reported higher concentration of ^{238}U, ^{232}Th and ^{40}K in a single layer, S3L4. It could be that the concentration of natural radionuclides in rock formation of granitic-gneiss intrusions in the study area is connected to metamorphosed processes of soil-rock formation during Pan-African events. It is noted that the thickness of higher concentration were at the depth ranging from 0 to 35 m. Borehole for consumption in the region should be cased to the bottom to prevent the higher dissolution of radionuclides from the near surface to the groundwater system. The identification of radioactive source rocks (porphyroblastic gneisses and biotite Hornblende granodiorite intrusions) that constitute higher concentrations of ^{238}U, ^{232}Th and ^{40}K in subsurface layers geologically, will address the professionals in hydrogeology and water resources management: civil engineers, environmental engineers, geologists and hydrologists who are engaged in the investigation, management, and protection of groundwater resources to choose a suitable site for drilling hydrogeologically motivated boreholes in basement terrain. The concentrations are within the limit and recommends further research within groundwater concentrations and environmental assessment of radiation risk at Kubwa area.

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References

1. Ivanovich M, Harmon RS (eds) (1982) Uranium series disequilibrium: application to environmental problems. Clarendon Press, Oxford
2. Langmuir D (1978) Uranium-solution equilibria at low temperatures with applications tosedimentary Ore deposits. Geochimica Cosmochimica Acta 42(6):547–569
3. Koljonen T (ed) (1992) The geochemical atlas of finland, Part 2: Till. Geological Survey of Finland, Espoo
4. Plant JA, Reeder S, Salminen R, Smith DB, Tarvainen T, De Vivo B, Peterson MG (2003) The distribution of uranium over Europe: geological and environmental significance. Appl Earth Sci 256(3):473–480
5. United Nations Scientific Committee on the effects of Atomic Radiation, UNSCEAR (2000) Sources, effect and risks of ionising radiation. Report to the General Assembly with Scientific Annexes United Nations, New York
6. Tzortzis M, Tsertos H (2004) Determination of thorium, uranium and potassium elemental concentrations in surface soils in Cyprus. J Environ Radioact 77:325–338
7. Xinwei L, Xiaolon Z (2008) Natural radioactivity measurements in rock samples of Chihua Mountain National Geological Park. China Radiat Prot Dosim 128:77–82
8. Lee, S K (2007) Natural background radiation in the Kinta District, Perak Malaysia. Masters thesis, Universiti Teknologi Malaysia, Faculty of Science
9. Pfenning G, Klewe-Nebenius H, Seelmann-Eggebert W (1998) Chart of the Nuclides. 6th edition revised reprint
10. Aieta EM, Singley JE, Trusell AR, Thorbjarnarson KW, McGuire MJ (1987) Radionuclides in drinking water: an overview. J Ameri water works Associ 79(4):144–152
11. Zapecza OS, Szabo Z (1986) Natural radioactivity in groundwater-a review U.S Geolog. Surv Water-Supply Paper 2325:50–57
12. Langmuir D (1978) Uranium-solution equilibria at low temperatures with applications to sedimentary Ore deposits. Geochi Cosmochi Acta 42(6):547–569
13. Saeed MA, Yusof SS, Hossain I, Ahmed R, Abdullah HY, Shahid M, Ramli AT (2012) Soil to rice transfer factor of the natural radionuclides in Malaysia. Rom J Phys 57(9–10):1417–1424 Bucharest
14. US Nuclear Regulatory Commission NRC (1988) Health risk of radon and other internally deposited alpha-emitters. Academia press; NRC Report BEIR IV, Washington, DC
15. Ajayi IR, Ajayi OS, Fusuyi AS (1995) The natural radioactivity of surface soil in Ijero-Ekiti. Nigeria Nig J Phys 7:101–103
16. Jibiri NN, Mabawonku AO, Oridate AA, Ujiagbedion (1999) Natural radionuclides concentration level in soil and water around a cement factory at Eweoro, Ogun Nigeria. Nig J Phy 11:12–16
17. Ajayi OS, Ajayi IR (1999) Environmental gamma radiation levels of some areas of Ekiti and Ondo State, South Western Nigeria. Nig J Phys 11:17–21
18. Godknows Igali (2012) Nigeria ranks 3rd in poor water access, by WHO and UNICEF. 11th session of development partners coordinating meeting, Daily Triumph Newspaper, May 10th
19. Maxwell O, Wagiran H, Ibrahim N, Lee SK, Soheil S (2013) Comparison of ^{238}U, ^{232}Th, and ^{40}K in different layers of subsurface structuresion Dei–Dei and Kubwa, Abuja Northcentral Nigeria. Radia Phys Chem 91:70–80
20. Oyawoye MO (1972) The basement complex of Nigeria. In Dessauvagie TFJ, Whiteman AJ (eds) African geology. Ibadan University Press, Ibadan , pp 66–102
21. Black RR, Caby R, Moussine-Pouchkine A, Bayer R, Bertrand JM, Boullier AM, Fabre J, Lesquer A (1979) Evidence for late precambrian plate tectonics in West Africa. Nature 278:223–227
22. Ajibade A, Woakes M, Rahaman M (1987) Proterozoic crustal development in the Pan-African regime of Nigeria. Geodynamics Series 17:259–271
23. Technical procedure, NYE county nuclear waste repository project office, TP-8.0, Rev. 15. (2003) field collection, logging, and processing of borehole geologic sample
24. Alnour I, Wagiran H, Ibrahim N, Laili Z, Omar M, Hamzah S, Idi BY (2012) Natural radioactivity measurements in the granite rock of quarry sites, Johor Malaysia. Radiati Physi Chem 81(12): 1842–1847
25. Ibrahim NM, Abd El Ghani AH, Shawky SM, Ashraf EM, Faruk MA (1993) Measurement of radioactivity level in soil in Nile Delta and Middle Egypt. Health Phys. 4:620–627
26. Hamby DM, Tynybekov AK (2002) Uranium, thorium, and potassium in soils along the shore of the lake Issyk-Kyol in the Kyrghyz republic. Environ Monit Assess 73:01–108
27. International Atomic Energy Agency,IAEA (1989) Construction and use of calibration Facilities for Radiometric Field Equipment. Technical Reports Series no.309, IAEA,Vienna
28. Eisenbud M, Gesell T (1997) Environmental radioactivity from natural industrial and military sources. Academic Press, San Diego, pp 134–200
29. Malczewski D, Sitarek A, Zaba J, Dorda J (2005) Natural radioactivity of selected crystalline rocks of Iera block. Prze Geol 53(3):237–244
30. United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR.(1998). Sources, effects and risks of ionising radiations. New York
31. Lee SK, Wagiran H, Ahmad TR, Nursama HA, Wood AK (2009) Radiological monitoring: terrestrial natural radionuclides in kinta district, perak. Malaysia J Environ Radioact. 100:368–374
32. Maxwell O, H Wagiran, Noorddin I, Oha IA, Onwuka OS, Soheil S (2014) Integrated geoelectrical and structural studies for groundwater investigation in some parts of Abuja, Northcentral Nigeria. Near Surface Geophysics, 12, doi:10.3997/1873-0604.2014007
33. Internal Commission on Radiological Protection (1991) Annual limits on intake of radionuclides by workers based on the 1990 recommendations. Annals on the ICRP, ICRP publication, 67, Oxford Press
34. Aviwiri GO (2005) Determination of radionuclide levels in soil and water around cement companies in port Harcourt. J Appl Sci Environ Mgt 9(3):27–29
35. Okeyedi AS, Gbadedo AK, Arowolo TA, Mustapa AO, Tehokossa (2012) Measurement of gamma-emitting radionuclides in rocks and soil of saunder quarry site, Abeokuta, Ogun State Nigeria. J Appl Sci 12(20):2178–2181
36. Cam NF, Yaprak G, Elen E (2010) The natural radioactivity contents in feed coal from the lignite-fired power plants in Western Anatola. Turk Radiat Prot Dosim 42(2–4):300–307
37. Saleh MA, Ramli AT, Alajerami Y, Aliyu AS (2013) Assessment of natural radiation levels and associated dose rates from surface soils in pontian district, Johor, malaysia. J Ovonic Res 9(1):17–27