Radiation Physics and Chemistry 91 (2013) 70–80

Contents lists available at SciVerse ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Comparison of activity concentration of ^{238}U, ^{232}Th and ^{40}K in different Layers of subsurface Structures in Dei-Dei and Kubwa, Abuja, northcentral Nigeria

Omeje Maxwell [a], Husin Wagiran [a,*], Noorddin Ibrahim [b], Siak Kuan Lee [c], Soheil Sabri [d]

[a] Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor Bahru, Johor, Malaysia
[b] Faculty of Defence Science and Technology, National Defence University of Malaysia, Kem Sungai Besi 57000, Kuala Lumpur, Malaysia
[c] Infocomm Research Alliance, Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor Bahru, Johor, Malaysia
[d] Department of Urban and Region Planning, Faculty of Built Environment, 81310 Johor Bahru,Universiti Teknologi Malaysia, Malaysia

HIGHLIGHTS

- Activity concentration of ^{238}U, ^{232}Th and ^{40}K was noted high.
- The two boreholes show significant different concentrations of ^{238}U,^{232}Th and ^{40}K.
- The Th/U ratio was high in both, but distinctly higher in first borehole.
- ^{232}Th was increasing with depth in site one almost 100%.
- The radiological monitoring on groundwater is recommended.

ARTICLE INFO

Article history:
Received 26 February 2013
Accepted 7 May 2013
Available online 23 May 2013

Keywords:
Geology
Abuja
Boreholes
Activity concentration
Gamma ray spectroscopy

ABSTRACT

The study of activity concentration of ^{232}Th, ^{238}U and ^{40}K of rock samples from site one (S1L1–S1L11, 70 m) and site two (S2L1–S2L9, 60 m) boreholes in Dei-Dei and Kubwa was presented and the first time in the region to be compared. Activity concentrations were analysed using a high resolution co-axial HPGe gamma ray spectrometer system. The activity concentration ranges in site one borehole were from 45 ± 1 to 98 ± 6 Bq kg^{-1} for ^{232}Th, from 18 ± 2 to 37 ± 4 Bq kg^{-1} for ^{238}U and from 254 ± 32 Bq kg^{-1} to 1195 ± 151 Bq kg^{-1} for ^{40}K. The activity concentration ranges in site two borehole were from 32 ± 3 to 84 ± 7 Bq kg^{-1} for ^{232}Th, from 15 ± 2 to 52 ± 5 Bq kg^{-1} for ^{238}U and from 119 ± 15 to 705 ± 94 for ^{40}K Bq kg^{-1}. Significantly higher concentration of ^{232}Th and ^{238}U occurs in samples collected from S1L7, S1L11 and S2L1 layers. These zones experienced granitic intrusions produced by denudation and tectonism. ^{40}K in rock samples of S1L4 and S2L4 activity concentrations is close; it could be that biotite granitic intrusion that is inferred as the formation in that layer reflects the same activity of potassium in rock's radioactivity measurement. The area requires further investigation of soil geochemistry and activity concentration of radionuclides in groundwater.

1. Introduction

Naturally occurring radioactive materials (NORM) are found throughout the earth's crust, and they form part of the natural background radiation to which all humans are exposed (U.S. Environmental Protection Agency, 1993). The presence of these (NORM) in soil, rocks, water, and air, along with cosmic radiation results in continuous and unavoidable internal and external radiation exposures of all human (United Nations Scientific Committee on the effects of Atomic Radiation, UNSCEAR, 2000). The NORM in the earth or soil and water of an environment are present as progeny of ^{238}U and ^{235}U and ^{232}Th isotopes distributed by natural geological and geochemical processes in addition to potassium ^{40}K and small quantities of fission-product residues such as ^{137}Cs from atmospheric weapon tests (Trimble 1968).

Epidemiological studies of uranium and non-uranium mines, for example, gold mines, have shown a high rate of lung cancer incidence, which is correlated with cumulative exposure to radon and its progeny (U.S. Nuclear Regulatory Commission, NRC, 1988). Extensive work has been carried out in many countries to evaluate the risks associated with NORM (U.S. Nuclear Regulatory Commission, NRC, 1988; United Nations Scientific Committee on the effects of Atomic Radiation, UNSCEAR, 2000). 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

* Correspondence author. Tel.: +607 5534002.
E-mail address: husin@utm.my (H. Wagiran).

0969-806X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.radphyschem.2013.05.006

originate in each area (United Nations Scientific Committee on the effects of Atomic Radiation, UNSCEAR, 2000, Tzortzis and Tsertos, 2004; Xinwei and Xiaolon, 2008; Abd El-Mageed et al., 2011).

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 (International Atomic Energy Agency (IEAE), 1989), while the average concentration of potassium in crustal rocks is approximately 2.5% with a range from 0.1% to 5% or more. Terrestrial natural radionuclides of soil and rocks in Kinta District, Perak, Malaysia reported high activity concentration of ^{238}U,^{232}Th and low activity concentration of ^{40}K (Lee et al., 2009).

In 2006, during limited field investigation (LFI) involving uranium in the subsurface at the Hanford Site's 300 Area, unexpectedly, high concentrations of uranium were discovered in groundwater samples collected at two of the four characterization boreholes (Williams et al., 2007). The samples were obtained during drilling and came from a stratigraphics interval in the unconfined aquifer that is not monitored by the existing well network. The occurrences appeared to be restricted to an interval of relatively finer-grained sediment within the Ring old Formation. The work involved drilling and characterization activities at four new locations near the initial discovery. This report presents the fresh information obtained since the LFI characterization report (Williams et al., 2007) regarding uranium contamination beneath the 300 Area. (Peterson et al., 2008) estimated that approximately 650,000 m^3 of groundwater beneath the 300 area investigated are affected by uranium at concentrations that exceed the drinking water standard of 30 μg/L.

In Nigeria, NORM levels have been studied in surface soils in Ijero-Ekiti (Ajayi et al., 1995), in soil and water around Cement Company in Ewekoro (Jibiri et al., 1999) and in rocks found in Ekiti (Ajayi and Ajayi, 1999). Only insignificant levels of NORM were identified by Ajayi et al. (1995)

The World Health Organization (WHO) and UNICEF report for 2012 ranks Nigeria the most populous country without adequate water and proper sanitation. The study area (Abuja) had a master plan 1979 which projected population figures in the region 5.8 million people by 2026. The recent population of Abuja is 2,759,829. It has an area coverage of 713 km^2 (275.3 sq mil) and density of 1091.9/km^2 (2828/sq mil).

The Abuja Water Board has a designed capacity with the pre-plan which is not in phase with the city growth in the recent. The increase in demand for water has led to compulsory alternative source to defray the deficit. 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 so many rock formations. The radioelement exists in this rock formation like granite to some extent which 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 radio-active elements. The objective of this study, therefore, is to determine the activity concentration of ^{238}U, ^{232}Th and ^{40}K in the lithological units to the aquiferous zone (groundwater-bearing rocks) of varying depth, 70 m and 60 m in Dei-Dei and Kubwa, respectively. Also, an estimation of radiological consequences on the public groundwater consumption possibly the effect through leaching from aquifer source rock will be made. The study areas are bounded by latitudes 8° 53′N–9° 13′N and longitudes 7° 00′E–7° 30′E. The towns are in the coordinates Lat.: 9° 6′52″N and Log: 7° 15′39″E (Dei-Dei) and Lat.: 9° 6′ 16.7″N and Lon.: 7° 16′ 26.0″E (Kubwa). 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.

Abuja under Koppen climate classification features a tropical wet and dry climate. The Federal Capital Territory Abuja experiences 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 north-east trade wind, with the main feature of dust haze, intensified coldness and dryness. The rainy season begins in April and ends in October. 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).

2. Geological and geophysical information of the study area

2.1. Geology and hydrogeology of the 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 Archaean 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. Detailed reports of the lithological description, age, history, structure and geochemistry of the Basement Complex of Nigeria are given in Oyawoye, 1972; Black et al., 1979; Ajibade et al., 1978; Rahaman, 1988; Caby, 1989, and Dada, 2008. Fig. 1 shows the google earth map of Abuja showing the location of the study areas and distance apart. Fig. 2 indicates with red arrow the location of Abuja on the geologic map of Nigeria.

In the study area, all the three major rock categories mentioned above are well represented in Fig. 3. The rocks are generally weathered into reddish micaceous sandy clay to clay materials, capped by laterite. The hydrogeology of 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 localized. This makes the search for a feasible borehole site imperative in the area.

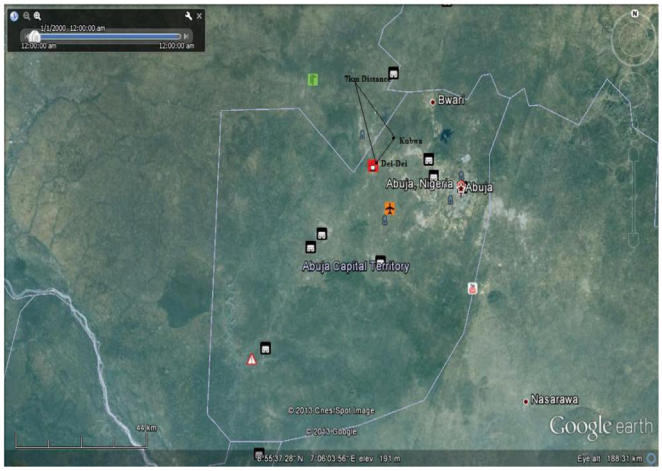

Fig. 1. Google earth map showing the study areas and distance apart.

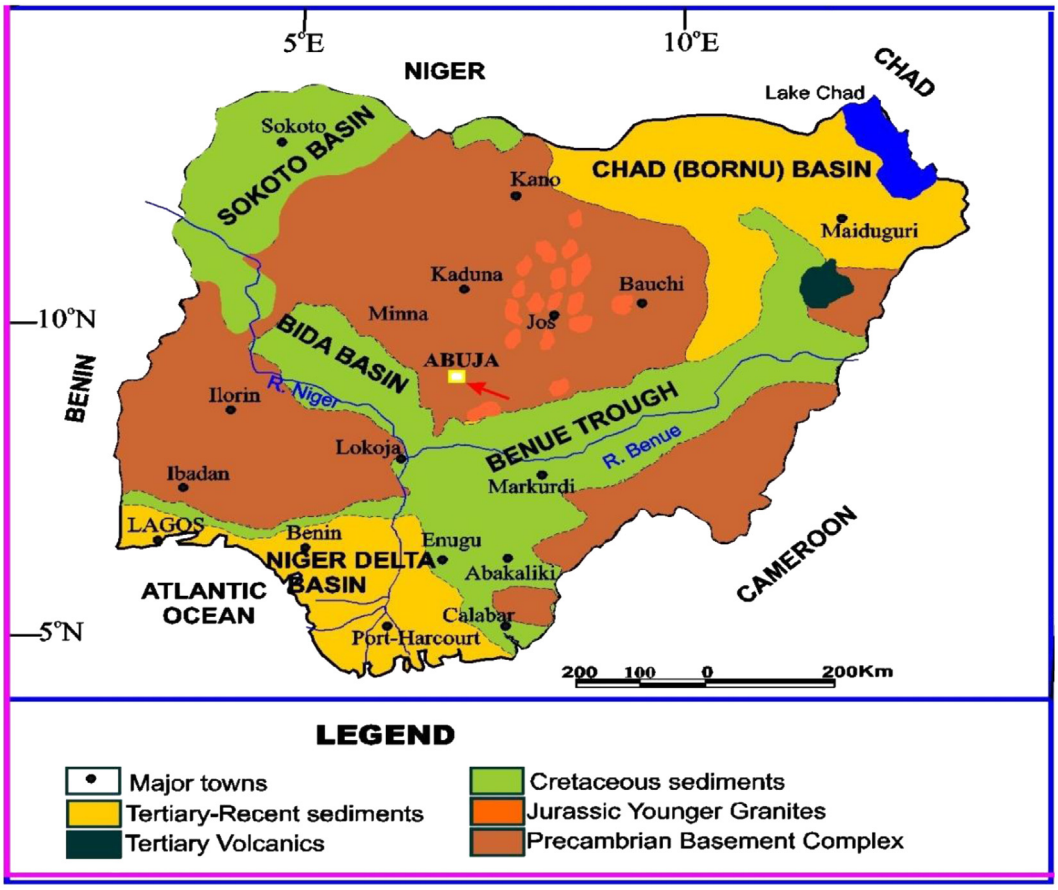

Fig. 2. Geological map of Nigeria, Showing the Position of Abuja (red arrow) in the Basement Complex of North Central Nigeria. (Modified from Obaje, 2009.) (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

Generally, the life span of boreholes is much lower in the area than in most areas that are underlain by porous sedimentary materials.

2.2. Geophysical investigation

Geophysical investigation was conducted to locate the suitable sites for drilling, also 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 dense populated zone. The geology of Abuja, therefore, makes the groundwater conditions in the area very unpredictable and requires thorough survey. Vertical Electrical Sounding (VES) (Barongo and Palacky, 1989; De Beer and Blume, 1985; Mbonu et al., 1991; Shemang, 1993) was carried out at 12 locations within and around the study area and the results integrated with structural data generated from hill shaded Shuttle Radar Topographic Mission (SRTM) data (Wright et al., 2006; Valeriano et al., 2006; Grohmann et al., 2007; Abdullah et al., 2012). Fig. 4 shows the VES points and the accessibility road to the area. The interpretation of the data obtained from the sounding 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. A total of 88 lineaments (fractures) were extracted from the hillshaded SRTM image (http://srtm.csi.cigar.org/) of the area, their orientation and distribution is represented on a lineament map and on a rose diagram, respectively, Figs. 5 and 6. The dominant fracture trend for the area is NNE–SSW and N–S, which corresponds to the Pan-African trends in the Basement Complex of Nigeria. The fractures exist and interconnect in Dei-Dei and Kubwa areas.

3. Materials and methods

3.1. Drilling boreholes

The boreholes were drilled with the help of 30 torn capacity Rig machine with compressor made of INGERSOL of 25 torn 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 of TP-8.0, Rev. 15 (2003) was employed.

3.2. Sample inventory

The identification of boundaries between layers with noticeably different particle sizes using visual manual logging method, record the thickness when the layer changes. Layer thickness change may range from less than one metres to tens of metres. After boundary of district layers has been clearly marked on plastic sock with an indelible felt-tipped pen, using a single entry for each layer

(a) Record the date the sample is logged and the initials of the logger.
(b) Record the sample type. For this sample, record “SL” to designate a geologically logged core segment, Site and Layer type.
(c) Determine and record the depth interval for each layer
(d) Photograph each layer using digital camera.

The two sites were Dei-Dei (69–70 m, 226.4–229.7 ft, S_1) and Kubwa (62–63 m, 203.4–206.7 ft, S_2), Figs. 4 and 5 show the drilling points.

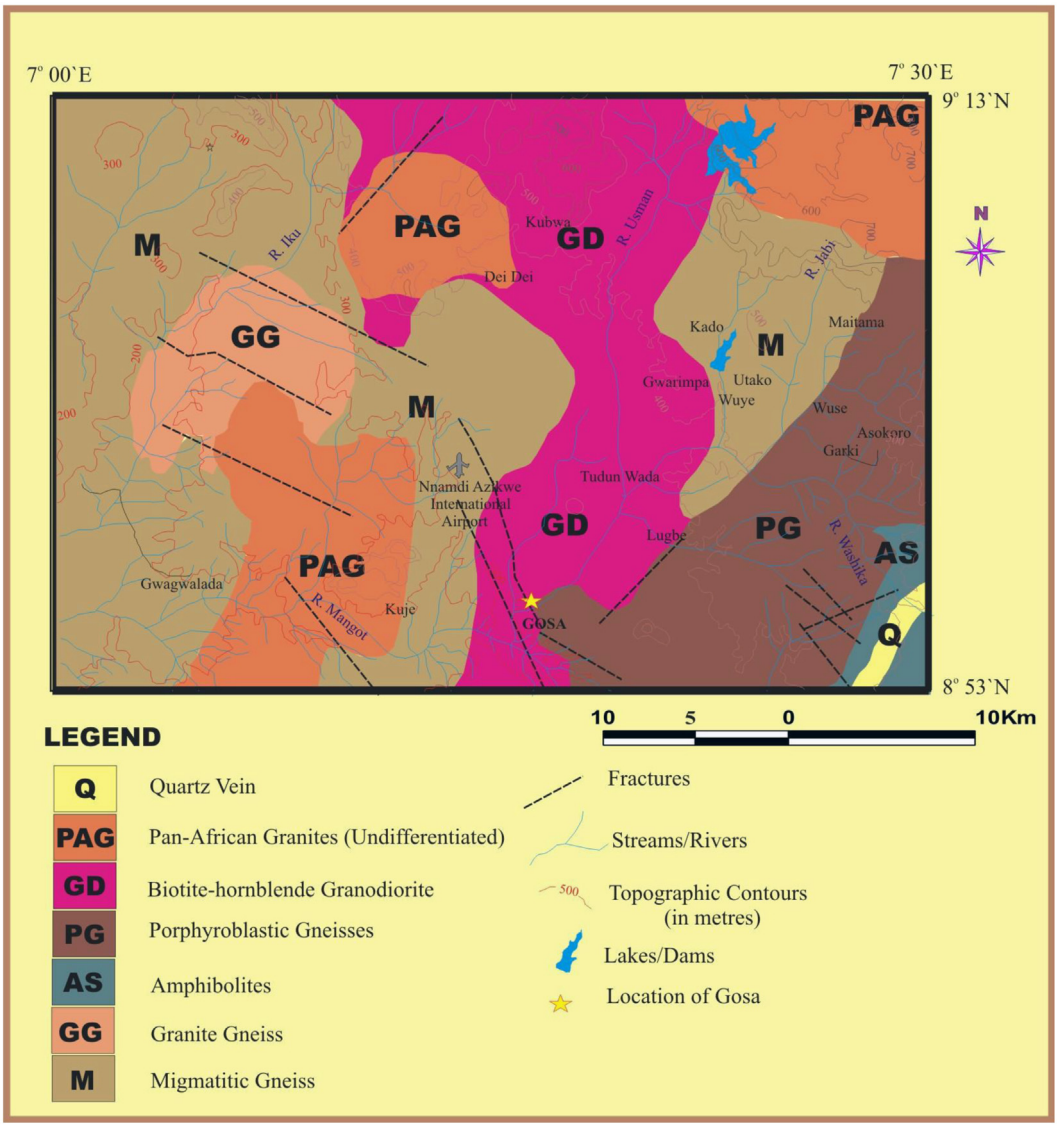

Fig. 3. Geological map of the study area.

Site one/Borehole one (S1): Eleven samples were collected from the drilling of well (S1). In addition, labelled using borehole number and depth. Details about the samples are listed in Table 1.

Site two/Borehole two (S2)*:* Nine samples were collected from the drilling well of (S2). Details about the samples are listed in Table 2.

3.3. Sampling and sample preparation

A total of 20 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 by Western Germany, crushed with the help of Bico Pulverizer MFD by Bico Inc. UA Burbank California. After crushing of each sample, high pressure compressor air with nozzle pipe was used to flush the remnant on the crushing machine and clean with tissue to avoid cross-contamination before adding another sample. It was crushed to powder and passed through 250 μm sieve mesh with the help of sieve shaker made of IMK11 Ende Cott Ltd, England. 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 four weeks to achieve secular equilibrium between radium and its progeny (Alnour et al., 2012a, 2012b; Ibrahim, 1993).

3.4. Experimental method for gamma-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 (FWHM) 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 (Tsoulfanidis, 1995).

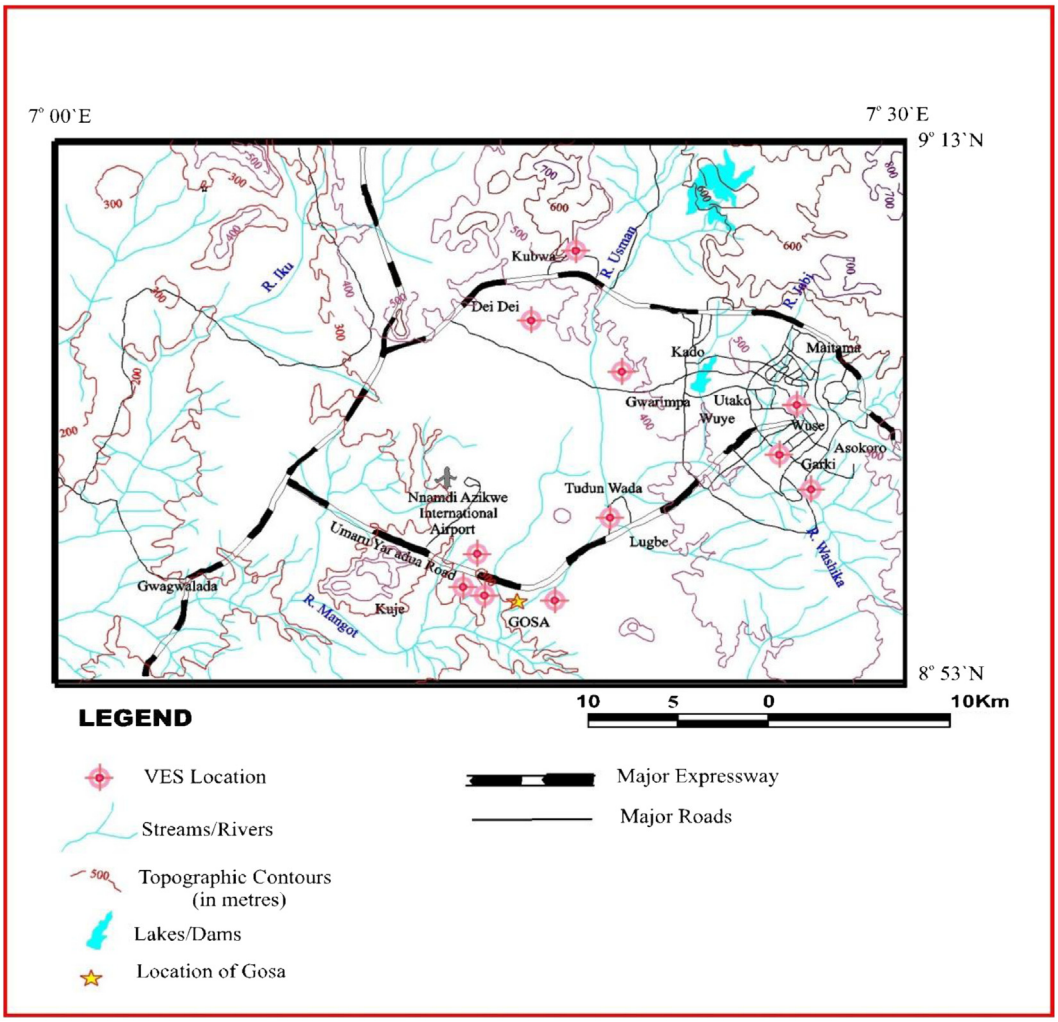

Fig. 4. Accessibility map of the study area with greenish dot at Dei-Dei and Kubwa, showing positions of VES points. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

Under the conditions of secular equilibrium, ^{232}Th concentration was determined from the average of ^{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 (Hemby and Tynybekov, 2002; Alnour et al., 2012a, b). The 1460 keV peak was used to determine the concentration of ^{40}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 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 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 SiO_2 in Marinelli beakers. The uranium and thorium content from S-14 are 29 ppm 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.

3.5. Calculation of the concentration of ^{238}U, ^{232}Th and ^{40}K

Calculations of count rates for each detected photopeak and radiological concentrations (activity per unit mass) of detected radionuclides depend on the establishment of secular equilibrium in the samples. Due to smaller life-time of the radionuclides in the decay series of ^{238}U and ^{232}Th, the ^{238}U concentration was determined from the average concentrations of the ^{214}Pb at 352 keV and ^{214}Bi at 609 keV in the sample, and that of ^{232}Th was determined from the average concentrations of ^{208}Tl at 583 keV and ^{228}Ac at 911 kev decay products (Hemby and Tynybekov, 2000). Thus, an accurate radiological concentration was made. The concentration of ^{40}K was based on 1460 keV peak.

The concentration of uranium and thorium can be calculated using the following formula:

$$C_{samp} = \frac{W_{std} \times N_{samp}}{W_{samp} \times N_{std}} . C_{std} \quad (1)$$

where

C_{samp} = concentration of sample collected (ppm)
C_{std} = concentration of the standard sample (ppm)
W_{std} = weight of the standard sample (g)
W_{samp} = weight of the sample collected (g)

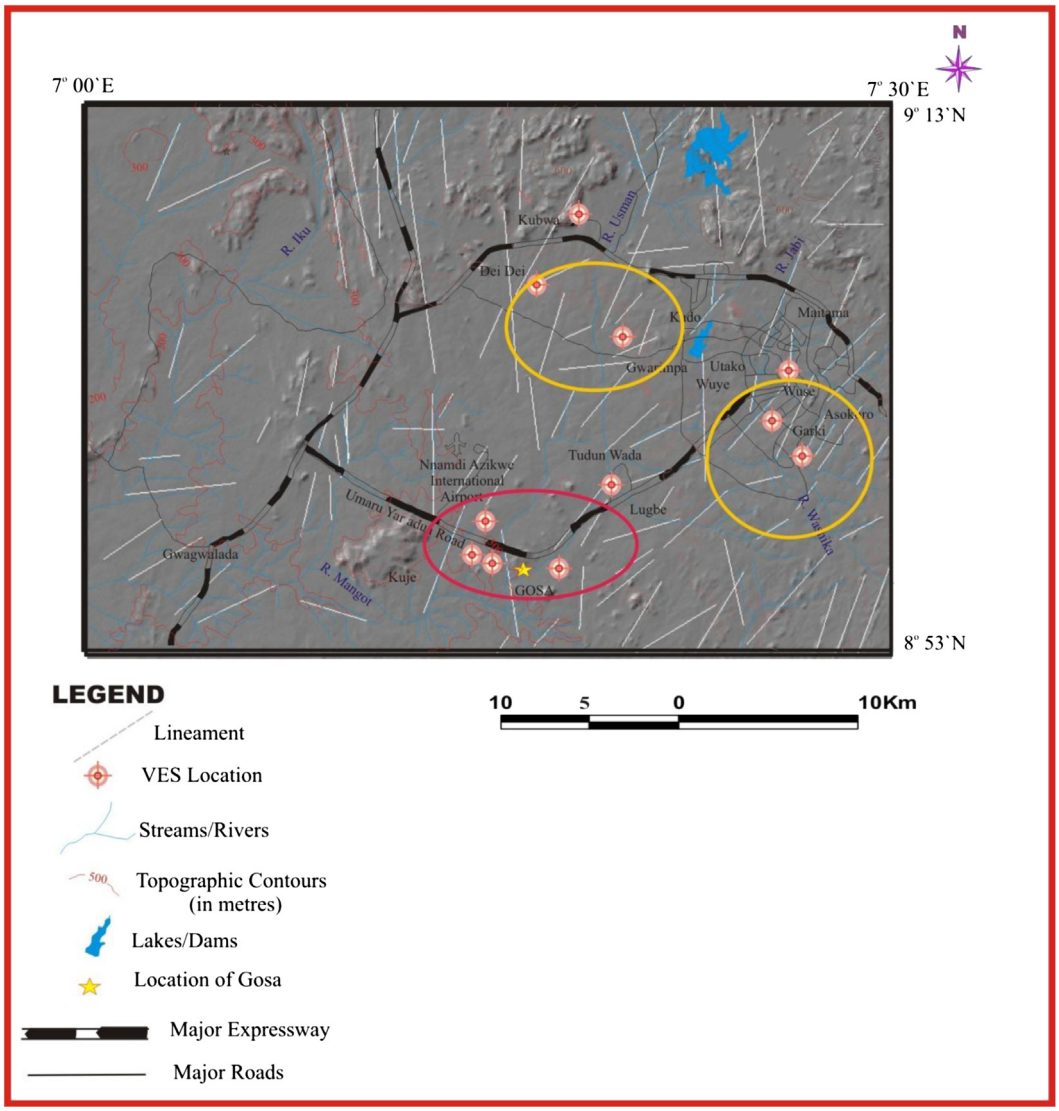

Fig. 5. Lineament map draped on Hill shaded SRTM-DEM image of the study area. Yellow ellipses show zones of higher fracture density and interception, whereas red ellipse shows low fractured density with non-interconnectivity. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

N_{samp} = net counts of the photopeak area of the sample collected
N_{std} = net counts of the photopeak area of the standard sample.

The uncertainty of the sample concentration could be calculated by using the following formula:

$$\Delta C_{\text{samp}}(\text{ppm}) = \left(\frac{\Delta W_{\text{std}}}{W_{\text{std}}} + \frac{\Delta W_{\text{samp}}}{W_{\text{samp}}} + \frac{\Delta N_{\text{samp}}}{N_{\text{samp}}} + \frac{\Delta N_{\text{std}}}{N_{\text{std}}}\right) \times C_{std} \quad (2)$$

Conversion factors were used to convert ppm to Bq kg^{-1} [^{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} (International Atomic Energy Agency (IEAE), 1989).

The specific activity of potassium can be calculated by using the formula:

$$A_{samp} = \frac{W_{std} \times N_{samp}}{W_{samp} \times N_{std}} A_{std} \quad (3)$$

where

A_{samp} = the specific activity of the sample collected (Bq kg^{-1})
A_{std} = the specific activity of standard sample (Bq kg^{-1})
W_{std} = the weight of the standard sample (Kg)
N_{samp} = the net counts of the photopeak area for the sample collected
W_{samp} = the weight of the sample collected (Kg)
N_{std} = the net counts of the photopeak area for the standard sample.

The uncertainty of the specific activity of potassium was calculated by using the following formula:

$$\Delta A_{samp}(ppm) = \left(\frac{\Delta W_{std}}{W_{std}} + \frac{\Delta W_{samp}}{W_{samp}} + \frac{\Delta N_{samp}}{N_{samp}} + \frac{\Delta N_{std}}{N_{std}}\right) \times A_{samp} \quad (4)$$

4. Results and discussion

4.1. Activity concentration of ^{232}Th, ^{238}U and ^{40}K in site one boreholes.

A summary of the average activity concentration of ^{238}U, ^{232}Th and ^{40}K in each layer from the borehole rock samples are in Tables 3–6.

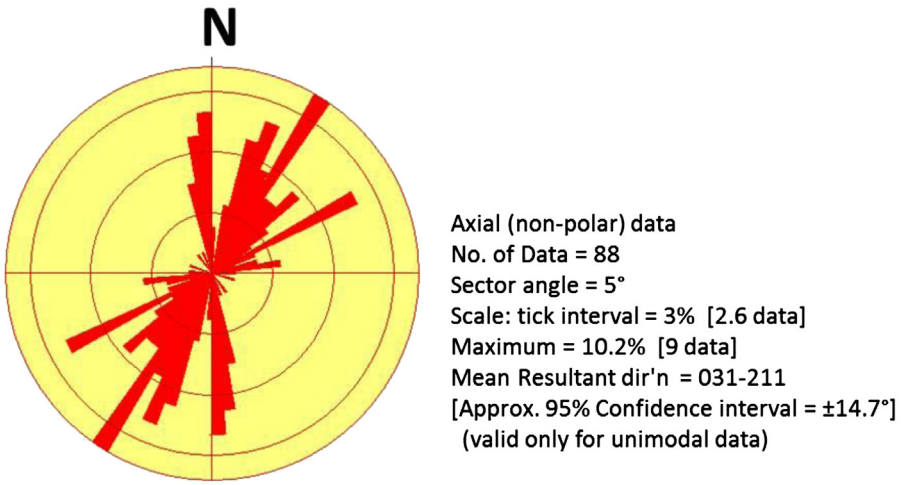

Fig. 6. Rose diagram showing the distribution of fracture orientations in the study area with NE–SW trend.

Table 1
Depth and lithologic unit of Site one borehole. The drilling point coordinate, Lat. 9° 6′52″N and Long. 7° 15′39″E, using GPS, Model: Extrex High Sensitivity 2000–2007 Garmin Ltd.

Sample ID	Depth (m)	Thickness (m)	Lithology description
S1L1	0–4	4	Sandstone, brownish and ferruginous, interbedded with quartz feldspar
S1L2	4–10	6	Coarse sand with clay, bright red.
S1L3	10–11.3	1.3	Slightly micaceous Sandy clay, brownish pebbly, fine to coarse feldspar.
S1L4	11.3–18.5	7.2	Fin to coarse sandy clayey and gravel
S1L5	18.5–24	5.5	Sand. brown, clayey at the top, fine to coarse
S1L6	24–33	9	Light grey coarse sand, granite gravel
S1L7	33–45	12	Silty sand feldspar, blackish to grey
S1L8	45–49	4	Grey silty sand, low grade
S1L9	49–57	8	Greyish to purple silty sand
S1L10	57–64.5	7.5	Sand, fine to coarse, pebbly blackish to grey
S1L11	64.5–71.7	7.2	Sand, fine to medium-grained, blackish to grey becoming whitish from 69 m

Table 2
Depth and lithologic unit of site two borehole. The drilling point coordinates, Lat. 9° 6′16.7″N and Long. 7° 16′26.0″E, using GPS, Model: Extrex High Sensitivity 2000–2007 Garmin Ltd.

Sample ID	Depth (m)	Thickness(m)	Lithology description
S2L1	0–7	7	Brownish ash sandy clay gravely interbedded.
S2L2	7–13.4	6.4	Clay with bright red.
S2L3	13.4–21	7.6	Sandy clay micaceous, brownish with feldspar.
S2L4	21–29	8	Fin to coarse sandy clayey and gravel smoky
S2L5	29–36.4	7.4	Clay sandy, fine grain size, darkish ash feldspar
S2L6	36.4–43	6.6	Silty clay, interbedded, bright ash to glacy feldspar.
S2L7	43–44	1	Fine to coarse ashy sandy clay.
S2L8	44–51	7	Fine to coarse sand, greyish.
S2L9	51–61.1	10.1	Micaceous – gravely sandy, fine-medium coarse darkish to grey.

In Tables 3–6, measured activity concentrations of ^{40}K, nuclides from ^{232}Th series (^{208}Tl, ^{228}Ac) and ^{238}U series (^{214}Pb, ^{214}Bi with ^{226}Ra) in investigated rock samples are presented. ^{238}U activity concentrations were calculated as the arithmetic means of the activities of ^{214}Pb and ^{214}Bi isotopes. In Table 3 concentrations of ^{40}K (%), ^{232}Th and ^{238}U (ppm) in measured samples calculated using conversion factors given by International Atomic Energy Agency (IEAE) (1989). The ^{232}Th and ^{238}U concentrations are based on the ^{238}Ac and ^{226}Ra activity concentrations, respectively. For all rocks Th/U ratio was calculated.

Data presented in Table 4 shows that radioactive equilibrium between progenies in ^{232}Th series for all rock samples can be assumed. Some measured rocks are characterized by very high values of activity concentrations of ^{228}Ac (^{232}Th). In sample collected from layers (S1L2) and (S1L8) have values close to the same level (45 ± 1 Bq kg^{-1} and 46 ± 4 Bq kg^{-1}), and distinctly low. The higher value refers to the sample from the depth to the bottom of aquifer bearing formation (S1L11), with the activity concentration of ^{228}Ac (^{232}Th) (98 ± 6 Bq kg^{-1}). Concentration of ^{232}Th in the investigated rocks varies in the range from 45 ± 1 Bq kg^{-1} to 98 ± 6 Bq kg^{-1} in the borehole layers. Noted activity concentrations are compared with average activity concentrations of ^{232}Th in the continental crust i.e. 44 Bq kg^{-1} and in the soil i.e. 37 Bq kg^{-1} (Eisenbud and Gesell, 1997). The highest measured value of ^{288}Ac (^{232}Th) activity concentration exceeds the average activity concentration refers to the continental crust almost twice (S1L11).

In site one, the highest values of ^{226}Ra (^{238}U) refer to the samples collected from the S1L5 and S1L7 (37 ± 4 Bq kg^{-1} and 37 ± 4 Bq kg^{-1}), respectively. Distinctly lower value was obtained from S1L8 (18 ± 2 Bq kg^{-1}). ^{238}U concentration varies from the

Table 3
The elemental concentration of ^{238}U, ^{232}Th (ppm) and ^{40}K (%) in site one borehole.

No.	Sample	Weight (g)	Concentration (ppm)		^{40}K	Th/U ratio
			^{238}U	^{232}Th		
1	S1L1	503.35	2.74 ± 0.26	13 ± 1	0.81 ± 0.10	4.75
2	S1L2	520.20	2.15 ± 0.21	11 ± 1	1.33 ± 0.16	5.19
3	S1L3	512.75	2.21 ± 0.21	13 ± 1	3.82 ± 0.48	5.73
4	S1L4	584.48	2.16 ± 0.21	14 ± 1	1.92 ± 0.24	6.39
5	S1L5	529.82	2.99 ± 0.29	18 ± 1	2.56 ± 0.32	5.87
6	S1L6	544.02	2.78 ± 0.27	16 ± 1	2.65 ± 0.33	5.92
7	S1L7	503.22	3.00 ± 0.29	19 ± 2	3.43 ± 0.43	6.35
8	S1L8	593.36	1.42 ± 0.14	11 ± 1	2.79 ± 0.35	8.05
9	S1L9	564.26	2.75 ± 0.26	24 ± 2	3.19 ± 0.40	8.59
10	S1L10	539.10	2.03 ± 0.20	19 ± 2	3.52 ± 0.44	9.45
11	S1L11	522.24	2.54 ± 0.20	24 ± 2	3.23 ± 0.44	9.49

Table 4
The activity concentration of ^{238}U, ^{232}Th and ^{40}K (Bq kg^{-1}) in site one borehole.

Sample ID	^{238}U	^{232}Th	^{40}K
S1L1	34 ± 3	53 ± 4	23236 ± 32
S1L2	27 ± 3	45 ± 2	415 ± 53
S1L3	27 ± 3	51 ± 4	1195 ± 151
S1L4	26 ± 3	56 ± 4	601 ± 76
S1L5	37 ± 4	71 ± 6	800 ± 101
S1L6	34 ± 3	67 ± 5	828 ± 104
S1L7	37 ± 4	77 ± 6	1073 ± 135
S1L8	18 ± 2	46 ± 4	874 ± 110
S1L9	34 ± 3	96 ± 8	997 ± 125
S1L10	25 ± 2	78 ± 6	1101 ± 139
S1L11	31 ± 2	98 ± 6	1010 ± 139
Mean	30 ± 3	67 ± 5	830 ± 103

Table 5
The activity concentration of ^{238}U, ^{232}Th (ppm) and ^{40}K (%) in site two borehole.

No.	Sample	Weight (g)	Concentration (ppm)		% ^{40}K	Th/U Ratio
			^{238}U	^{232}Th		
1	S2L1	503.35	4.19 ± 0.40	21 ± 2	0.38 ± 0.05	4.95
2	S2L2	520.20	1.86 ± 0.18	8 ± 1	1.27 ± 0.16	4.22
3	S2L3	512.75	2.64 ± 0.25	14 ± 1	1.94 ± 0.25	5.37
4	S2L4	584.48	3.16 ± 0.30	9 ± 1	2.03 ± 0.26	2.89
5	S2L5	529.82	1.19 ± 0.12	10 ± 1	1.63 ± 0.20	8.36
6	S2L6	544.02	2.78 ± 0.27	17 ± 1	2.25 ± 0.28	6.14
7	S2L7	503.22	3.46 ± 0.33	19 ± 2	2.22 ± 0.27	5.52
8	S2L8	593.36	3.26 ± 0.31	19 ± 2	2.36 ± 0.30	5.86
9	S2L9	564.26	2.52 ± 0.24	17 ± 1	2.40 ± 0.30	6.83

range of 18 ± 2 Bq kg^{-1} to 37 ± 4 Bq kg^{-1}, respectively. For comparison, the arithmetic mean of the activity concentrations of ^{238}U from lower Silesia equals 35 Bq kg^{-1}. ^{238}U activity concentrations in granite from SzKlarska poreba (Karkonosze granite) vary in the wide range from 15 to 119 Bq kg^{-1} whereas in aplite and in mica schist from SzKlarska Poreba ^{238}U activity concentrations equal 66 ± 6 Bq kg^{-1} and 54 ± 9 Bq kg^{-1}, respectively (Przylibski, 2004). Concentration of ^{238}U in investigated rocks calculated with assumption of radioactivity equilibrium in uranium series varies in the range from 18 ± 2 Bq kg^{-1} (S1L8) to 37 ± 4 Bq kg^{-1} (S1L5). Comparing the activity concentrations of ^{238}U with the average activity concentrations of ^{238}U reported for the continental crust i. e. 36 Bq kg^{-1} and for soil i.e. 22 Bq kg^{-1}(Eisenbud and Gesell, 1997). For each case, the average activity concentrations of ^{238}U were in the range except S1L5 and S1L7, noted higher and S1L8, distinctly lower.

Table 6
The activity concentration of ^{238}U, ^{232}Th and ^{40}K in (Bq kg^{-1}) in site two borehole.

Sample	^{238}U	^{232}Th	^{40}K
S2L1	52 ± 5	84 ± 7	119 ± 15
S2L2	23 ± 2	32 ± 3	399 ± 51
S2L3	33 ± 3	58 ± 5	605 ± 77
S2L4	39 ± 4	37 ± 3	636 ± 81
S2L5	15 ± 1	40 ± 3	510 ± 64
S2L6	34 ± 3	69 ± 5	705 ± 89
S2L7	43 ± 4	78 ± 6	695 ± 88
S2L8	40 ± 4	77 ± 6	738 ± 93
S2L9	31 ± 3	70 ± 6	750 ± 94
Mean	34 ± 3	61 ± 5	573 ± 72

As shown in Table 4, ^{40}K activity concentrations for all the rock samples are greater than 200 Bq kg^{-1}. In first and second layer, the activity concentrations of the radionuclide do not differ much, but the lowest value was noted in first layer, S1L1 (236 ± 32 Bq kg^{-1}), whereas the highest value refers to the sample layer three (1195 ± 151 Bq kg^{-1}), respectively. The range varies from 240 ± 32 Bq kg^{-1} to 1195 ± 151 Bq kg^{-1} in the first borehole site. In contrast with the range of the average activity concentrations of ^{40}K reported for the continental crust i.e. 850 Bq kg^{-1} and for soil i.e. 400 Bq kg^{-1} (Eisenbud and Gesell, 1997), it can be seen that measured activity concentrations associated with ^{40}K decay are distinctly higher than the average concentration of this isotope in the continental crust for all samples. The percentage is higher in layer three, S1L3 (3.82%). The plot of activity concentration of ^{232}Th, ^{238}U and ^{40}K versus sample ID of site one is presented in Fig. 7, showing almost 100% ^{232}Th increase with depth.

The Th/U ratio varies in the range from 4.75 to 9.49. The highest value refers to layer 11 (S1L11), whereas the lowest value was noted in the sample collected from first layer, laterite top soil, S1L1. Obtained Th/U concentration ratios are very high, higher than data published in literature concerning rocks of Karkonosze-Irera block. For example, in hornfel from Death Bend area, Th/U equals 3 and Th/U concentration ratio in rocks in the environs of Swieradow Zdroj varies between 1.5 and 3.2 (Malczewski et al., 2005).

Th/U concentration ratio given by Eisenbud and Gesell (1997) for the continental crust equals 1.2 and for granite is 1.8. Cited values are distinctly lower than Th/U concentration ratio obtained for investigated rock samples from Site one Borehole. Even value of Th/U ratio measured in granite from Szklarska Poreba that equals 3.2 (Plewa and Plewa, 1992). Obtained results suggest that very high content of ^{228}Ac (^{232}Th) and high content of ^{226}Ra (^{238}U) in investigated rock samples are connected where rocks formed were due to thermal metamorphism and metasomatic processes occur. These processes seem to be responsible for so high level of radioactivity of rocks but it needs further geochemical research and activity concentration in groundwater. The highest value of Th/U concentration ratio refers to the deepest layer up to 70 m, S1L11. The lowest values of ^{228}Ac (^{232}Th) and ^{226}Ra (^{238}U) activity concentrations (Th/U) were measured in rock sample collected at the laterite top soil of depth about 6 m thick. In this case, the lowest difference between concentrations of ^{232}Th and ^{238}U among the other rock samples.

4.2. Activity concentration of ^{232}Th, ^{238}U and ^{40}K in site two borehole

Data presented in Table 6 shows that the higher activity concentration of ^{228}Ac (^{232}Th) refers to (S2L1), with the value (84 ± 7 Bq kg^{-1}). In sample collected from layers (S2L2) has value (32 ± 3 Bq kg^{-1}), and distinctly lower. It was observed that S2L7 and S2L8 activity concentrations of ^{232}Th are close (78 ± 6 and

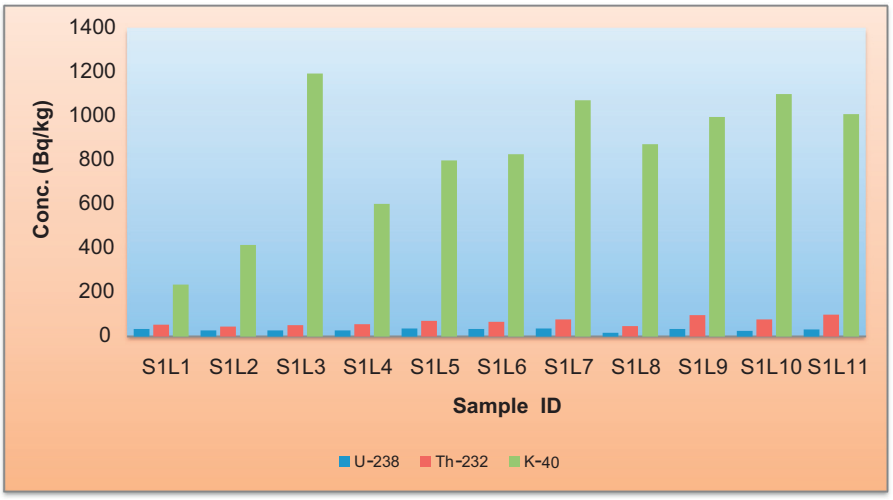

Fig. 7. Plot of activity concentration of ^{238}U, ^{232Th} and ^{40}K versus sample layers ID in first borehole S1L1–S1L11 (Dei-Dei), Abuja.

77 ± 6 Bq kg^{-1}). Concentration of ^{232}Th in the investigated rocks vary in the range from 32 ± 3 Bq kg^{-1} to 84 ± 7 Bq kg^{-1}. Also, the activity concentration of ^{232}Th in S2L4 and S2L5 are close to each other (37 ± 3 and 40 ± 3 Bq kg^{-1}). Note activity concentrations are compared with average activity concentrations of ^{232}Th in the continental crust as reported by Eisenbud and Gesell (1997). The measured value of Ac (^{232}Th) activity concentration in (S2L1) exceeds the average activity concentration refers to the continental crust almost twice.

Measured rocks are characterized by radioactivity of ^{226}Ra (^{238}U). The highest value refers to the sample collected from S2L1 (52 ± 5 Bq kg^{-1}). Distinctly lower value was obtained from S2L5 (15 ± 1 Bq kg^{-1}). ^{238}U concentration in site two Borehole varies from the range of 15 ± 1 Bq kg^{-1} to 52 ± 5 Bq kg^{-1}, respectively. For comparison the (Przylibski, 2004) for ^{238}U is stated above. Concentration of ^{238}U in investigated rocks calculated with assumption of radioactivity equilibrium in uranium series varies in the range from 15 ± 1 Bq kg^{-1} (S2L5) to 52 ± 5 Bq kg^{-1} (S2L1). Measured activity concentrations of ^{226}Ra (^{238}U) were compared with the average activity concentrations of ^{238}U reported by (Eisenbud and Gesell, 1997).The average activity concentrations of ^{238}U are higher except in samples (S2L2, S2L3, S2L5 and S2L9), respectively.

As shown in Table 6 and Fig. 8, ^{40}K activity concentrations for all the rock samples are greater than 100 Bq kg^{-1}. The activity concentrations of the ^{40}K did not differ much, but the lowest value was noted in first layer, S2L1 (119 ± 15 Bq kg^{-1}), whereas the highest value refers to the sample layer nine, S2L9 (750 ± 94 Bq kg^{-1}), respectively. The range varies between 118 Bq kg^{-1} and 750 Bq kg^{-1} in site two. In contrast with the range of the average activity concentrations of ^{40}K reported by (Eisenbud and Gesell, 1997), it can be seen that measured activity concentrations associated with ^{40}K decay are distinctly lower than the average concentration of this isotope in the continental crust for some samples in site two Borehole.

The Th/U ratio varies in the range from 2.89 to 8.36. The highest value refers to layer five (S2L5), whereas the lowest value was noted in the sample collected from fourth layer, S2L4. Obtained Th/U concentration ratios are higher than data published in literature concerning rocks of Karkonosze-Irera block, by Malczewski et al. (2005). Also, higher than the Th/U concentration ratio given by Eisenbud and Gesell (1997). In cited literatures, the values are distinctly lower than Th/U concentration ratio obtained for investigated rock samples from Site two borehole.

4.3. Comparison of activity concentration of ^{232}Th, ^{238}U and ^{40}K in site one and site two boreholes

1. The activity concentrations of ^{232}Th in Site one is noted higher in layer 11 (S1L11) whereas in site two borehole, it was noted in layer one (S2L1). The lowest value in site one was in layer two (S1L2) and in site two the lowest value was in (S2L2). Both layers (S1L2 and S2L2) may appear to have the same deposition of sediments and could have the same geologic rock type, but differ in ^{238}U due to its oxidation characteristics. Site one requires further research on activity concentration of ^{232}Th in groundwater whereas site two requires environmental radioactivity survey of surface soil.
2. The activity concentration of ^{238}U in both boreholes varies. In site one, the highest value is noted in layer seven (S1L7) whereas in site two, is in (S2L1). This is due to soil type and the mobility characteristic of ^{238}U in subsurface sediment. The lower value in site one borehole is noted in eight layer (S1L8) whereas in second site borehole, it was noted in fifth layer (S2L5). Further research of subsurface rock geochemistry is required in site one and environmental studies of surface radionuclide is require in site two location.
3. The activity concentration of ^{40}K in site one is higher in layer three (S1L3) and in site two was noted in ninth layer (S2L9). The contradicting result here is that the lower values of ^{40}K was noted in first layers of both site one and site two (S1L1 and S2L2). This could be attributed to low colloidal sediments in near surface of both sites.

Moreover, a comparison of the activity concentrations of uranium, thorium and potassium in the present study with previous studies are presented in Table 7. 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 show a good agreement with those reported in previous studies. In general, all results existed within the range given in United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR (1998).

5. Conclusion

The results of gamma-ray measurements presented in this paper give current information about natural radioactivity variation in

Table 7
Summary of activity concentration of radioisotopes in soil samples in Dei-Dei and Kubwa Abuja and other Parts of the World (United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR, 1998).

Region/country	^{232}Th (Bq kg^{-1})		^{238}U (Bq kg^{-1})		^{40}K (Bq kg^{-1})	
	Range	Mean	Range	Mean	Range	Mean
Dei-De1,Abuja,Nort Central Nigeria[a]	45–98	67	18–37	30	119–750	830
Kubwa, Abuja, Northcental Nigeria[a]	32–84	61	15–52	34	236–1195	573
Ikogosi-Ekiti, South western Nigeria[b]	1–108	82	4–111	58	40–2437	1203
Malaysia[c]	63–110	82	49–86	66	170–430	310
China[c]	1–360	41	2–690	84	9–1800	440
India[c]	14–160	64	7–81	29	38–760	400
Japan[c]	2–88	28	2–59	29	15–990	310
United State[c]	4–130	35	4–140	35	100–700	370
Egypt[c]	2–96	18	6–120	37	29–650	320
Greece[c]	1–190	20	1–240	25	12–1570	360
Portugal[c]	22–100	51	26–82	49	220–1230	840
Russia[c]	2–79	30	0–67	19	100–1400	520
Spain[c]	2–210	33	–	–	25–1650	570
World[d]	7–50	45	16–116	33	100–700	420

[a] Present study.
[b] Ajayi (1999).
[c] United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR (1998).
[d] United Nations Scientific Committee on the effects of Atomic Radiation, UNSCEAR (2000).

Fig. 8. Plot of activity concentration of ^{238}U, ^{232Th} and ^{40}K versus sample layers ID in second borehole S2L1–S2L9 (Kubwa), Abuja.

layers of varying depths. This is the first subsurface radioactive investigation in the region. In this study, several current activity concentrations of ^{232}Th, ^{238}U and ^{40}K are presented with geological, geophysical and geodynamical attributes. In the case of rock samples collected from site two, where both activity concentrations of ^{232}Th and ^{238}U in (S2L1) at the laterite topsoil are distinctly higher or twice the report from a literature reported (Eisenbud and Gesell, 1997) and in site one borehole with the values of ^{232}Th and ^{238}U in different layers (S1L11 and S1L7). This variation or instability of activity concentration of radionuclides with depth is a function of lithological, structural, topographic and climatic factors which work synergistically. In S1L7 layer could be attributed to the mobility of ^{238}U in oxidizing condition.

^{40}K in rock samples of S1L4 and S2L4 activity concentrations is close; it could be that biotite granitic intrusion that is inferred as the formation in that layer reflects the same activity of potassium in rock's radioactivity measurement. It needs further measurements in other locations.

As obtained results show granitic intrusion and weathered micaceous sandstone could determine high radioactivity of rocks formed in the area due to thermal metamorphism. In site one borehole, the concentration of ^{232}Th was increasing up to 100% with depth, Fig. 7, except the deformed and fractured terrain at layer eight (S1L8) that could have shared its ^{232}Th concentration to the neighbouring layers (S1L7 and S1L9). It requires further measurements of radionuclides and geochemical investigation. The layers in the region may have encountered more effect of tectonic activities that resulted to magmatic interbedding. In all rock samples, very high activity concentrations associated with decay of ^{232}Th and ^{238}U series were observed. These values in some layers twice exceed the average activity concentrations refer to continental crust and are distinctly higher than world report in United Nations Scientific Committee on the effects of Atomic Radiation, UNSCEAR (2000), Table 7. Based on our measurements, it could be noted that concentration of ^{232}Th and ^{238}U in measured rocks depends on the distance between sample place and the nature of the intrusive materials or the cross-bedding with magmatic and metasediments.

Significantly higher concentration of ^{232}Th and ^{238}U occurs in samples collected from S1L7, S1L11 and S2L1 layers. These zones

experienced granitic intrusions produced by denudation and tectonism. So the majority of the radionuclides genetically connected with granitic intrusion built into metamorphosed rocks in the closest vicinity of the intrusion but should be further researched with activity concentration in groundwater and geochemical investigations.

Acknowledgement

The authors would like to thank the ministry of Higher Education (MOHE) for their funding through Universiti Teknologi Malaysia Research Grant Scheme Project number: Q.J130000.2526.03H28. The authors will gratefully acknowledge the Nigerian Geological Survey Agency and Federal Ministry of Water Resources for their support in this work. Thanks to SYB Sinyoung Borehole Limited for providing the Rig machine and Compressor used in drilling the boreholes. Also, to Maxico Hydrosolution consult for providing Campus Ohmega for geosurvey. Finally, acknowledged the UTM laboratory staff, Saiful Rashid, Johari Zainudin, Mohd Jaafar Raji and Anisa Salikin.

References

Abd El-Mageed, I.A., El-Kamel, H.A., Abbady, A., et al., 2011. Assessment of natural and anthropogenic radioactivity levels in rocks and soils in the environments of Juban town in Yemen. Radiat. Phys. Chem. 80, 710–715.

Abdullah, K., Sarfaraz, A., Shadab, K., 2012. Geology and geomorphology of the Manipur Valley using digitally enhanced satellite image and SRTM DEM in the Eastern Himalaya, India. Int. J. Geosci. 3, 1010–1018.

Ajayi, I.R., Ajayi, O.S., Fusuyi, A.S., 1995. The natural radioactivity of surface soil in Ijero-Ekiti, Nigeria. Niger. J. Phys. 7, 101–103.

Ajayi, O.S., Ajayi, I.R., 1999. Environmental gamma radiation levels of some areas of Ekiti and Ondo State, South Western Nigeria. Niger. J. Phys., 11; pp. 17–21.

Ajibade, A.C., Woakes, M., Rahaman, M.A., 1978. Proterozoic crustal development in the Pan-African regime of Nigeria. In: Proterozoic lithospheric evolution geodynamics, 17, pp. 259–271.

Alnour, A.I., Ibrahim, N., Hossain, I., 2012a. Concentration of 214Pb, 214Bi in 238U series and 208Tl, 228Ac in 232Th series in granite rock in (Kadugli) Sudan. Indian J. Pure Appl. Phys. 50, 285–682.

Alnour, A.I., Wagiran, H., Ibrahim, N., Laili, Z., Omar, M., Hamzah, S., Bello, Y.I., 2012b. Natural radioactivity measurements in the granite reock of quarry sites, Johor, Malaysia. Radiat. Phys. Chem. 81, 1842–1847.

Barongo, J.O., Palacky, G.D., 1989. Investigation of electrical properties of weather layers in the Yale area, Western Kenya, using resistivity soundings. Geophysics 56, 133.

Black, R.R., Caby, R., Moussine-Pouchkine, A., Bayer, R., Bertrand, J.M., Boullier, A.M., Fabre, J., Lesquer, A., 1979. Evidence for Late Precambrian plate tectonics in West Africa. Nature 278, 223–227.

Caby, R., 1989. Precambrian terrains of Benin, Nigeria and Northeast Brazil and the Late Proterozoic South Atlantic fit. Geologic Society of American Special Paper. vol. 230, pp. 145–158.

Dada, S.S., 2008. Proterozoic evolution of the Nigeria – Boborema province. Geol. Soc. London 294, 121–136.

De Beer, J.H., Blume, J., 1985. Geophysical and hydrogeological investigation of the groundwater resources of western Hereroland, southwest African/Namibia. Trans. Geol. Soc. S. Afr. 88, 483–493.

Eisenbud, M., Gesell, T., 1997. Environmental Radioactivity from Natural, Industrial and Military Sources. Acad. press, San Diego, CA pp. 134–200.

Grohmann, H.C., Riccomini, C., Machado-Alves, F., 2007. SRTM-based morphotectonic analysis of the Pocos de Caldas Alkaline massif, Southern Brazil. Comput. Geosci. 33, 10–19.

Hemby, D.M., Tynybekov, A.K., 2002. Uranium, Thorium and Potassium in soils along the shore of the lake Issyk-Kyol in the Kyrghyz Republic. Environ. Monit. assess 73, 101–108.

Ibrahim, N.M., Abd El Ghani, A.H., Shawky, S.M., Ashraf, E.M., Farouk, M.A., 1993. Measurement of radioactivity level in soil in Nile Delter and Middle Egypt. Health Phys. 4, 620–627.

International Atomic Energy Agency (IEAE), 1989. Construction and Use of Calibration Facilities for Radiometric Field Equipment. Technical Reports Series no. 309, IAEA, Vienna.

Jibiri, N.N., Mabawonku, A.O., Oridate, A.A., ujiagbedion, 1999. Natural radionuclides concentration level in soil and water around a cement factory at Eweoro, Ogun, Nigeria. Nig. J. Phys. 11, 12–16.

Lee, S.K., Wagiran, H., Ahmad, T.R., Nursama, H.A., Wood, A.K., 2009. Radiological monitoring: terrestrial natural radionuclides in Kinta District, Perak, Malaysia. J. Environ. Radioact. 100, 368–374.

Malczewski, D., Sitarek, A., Zaba, J., Dorda, J., 2005. Natural radioactivity of selected crystalline rocks of Iera block. Prze. Geol. 53 (3), 237–244.

Obaje, N.G., 2009. Geology and mineral resources of Nigeria. In: Lecture Notes in Earth Sciences, vol. 120, pp. 221.

Oyawoye, M.O., 1972. The basement complex of Nigeria. In T.F.J. Dessauvagie and A.J. Whiteman (Eds.). Africican Geology, Ibad. pp. 66–102.

Peterson, R.E., Serne, R.J., Thorne, P.D., Williams, M.D., Rock hold, M.L., 2008. Uranium Contamination in the Subsurface Beneath the 300 Areas, Hanford Site, Washington. PNNL-17034, Paci. Nort. West. Natio. Lab., Richl., Washington.

Plewa, M. Plewa, S., 1992. Petrofizyka, Wydamnictwa Geologiczne, Warszawa, pp. 248–271.

Przylibski, T., 2004. Concentration of 226 Ra in rocks of Southern part of Lower Silesia, SW Poland. J. Environ. Radioact. 75, 171–191.

Rahaman, M.A., 1988. Recent advances in the study of the Basement Complex of Nigeria. Precambrian Geology of Nigeria. Geol. Surv. Niger. Pub., 11–43.

Shemang, E.N., 1993. Groundwater potentials of Kubami River Bassin, Zaria, Nigeria, from D. C Resistivity study. Water Resour. 2, 36–41.

Technical Procedure, NYE County Nuclear Waste Repository Project Office (TP-8.0, Rev. 15), 2003. Field Collection, Logging, and Processing of Borehole Geologic Sample.

Trimble, C.A. 1968. Absolute Counting of Alpha Decay and the Radioactivity in Water from Hot Spring National Park, University of Arkansas, Thesis.

Tsoulfanidis, N., 1995. Measurement and Detection of Radiation. Taylor and Francis.

Tzortzis, M., Tsertos, H., 2004. Determination of thorium, uranium and potassium elemental concentrations in surface soils in Cyprus. J. Environ. Radioact. 77, 325–338.

U.S. Environmental Protection Agency, 1993. Diffuse NORM Waste Characterization and Preliminary Risk Assessment, Washington, DC, U.S. EPA, RAE-9232/1-2, Draft Report.

U.S. Nuclear Regulatory Commission, NRC, 1988. Health Risk of Radon and Other Internally Deposited Alpha-Emitters. Academia press, Washington, DC, NRC Report BEIR IV.

United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR, 1998. Sources, Effects and Risks of Ionising Radiations. New York.

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.

Valeriano, M.M., Kuplich, T.M., Storino, M., Amaral, B.D., Mendes, J.N., Lima, D.J., 2006. Modelling small watersheds in Brazilian Amazonia with shuttle radar topographic mission 90 m data. Comput. Geosci. 32, 1169–1181.

World Weather Information service-Abuja, World Meteorological Organization. Retrived October 1st, 2012. < http://en.wikipedia.org/wiki/Abuja > .

Williams, B.A., Brown, C.F., UM, W., Nimmons, J., et al., 2007. Limited Field Investigation Report of Uranium Contamination in 300 Areas, 300-FF-5 Operable Unit, Hanfold Site, Washington. Paci. Nort. Wes. Natio. Lab., Ric., Washington.

Wright, R., Garbeil, H., Baloga, S., Mougin-Mark, P., 2006. An assessment of shuttle radar topographic mission digital elevation data for studies of volcano morphology. Rem. Sens. Environ. 105, 41–53.

Xinwei, L., Xiaolon, Z., 2008. Natural radioactivity measurements in Rock samples of Chihua Mountain National Geological Park, China. Radiat. Prot. Dosim. 128, 77–82.