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Spatial distribution of natural radionuclides and its radiological impact in a fractured sedimentary zone, Nupe basin north-central Nigeria

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Abstract

High-resolution aero-radiometric data were analysed over a fractured sedimentary zone to determine the concentrations of natural radionuclides (^{238}U , ^{232}Th , and ^{40}K), and to evaluate radiological hazard indices. This was done to assess the potential levels of risk associated with exposure to these radionuclides. The data, covering selected parts of the Nupe Basin, were obtained from the Nigeria Geological Survey Agency (NGSA) and analysed using Oasis Montaj software. Results showed that the activity concentration of uranium, thorium, and potassium in all the locations ranges from 3.7 ± 0.14 Bq/Kg to 1323.5 ± 3.00 Bq/Kg, and the average value of uranium, thorium and potassium are 35.3 ± 0.07 Bq/Kg, 48.88 ± 0.15 Bq/Kg, and 179.9 ± 0.21 Bq/Kg respectively. In addition, analyses of the radiological hazard indices showed that the average value of the absorbed dose rate, annual effective dose, and excess lifetime cancer risk are 53.38 ± 0.18 nGy/h, 0.065 ± 0.02 mSv/y, and $1.85\text{E-}4 \pm 0.2\text{E-}4$ as against the recommended values of 84 nGy/h, 1mSv/y, and $3.75\text{E-}3$ respectively. However, a comparison of the radiological hazard indices with the recommended permissible limits shows that the average values remain within acceptable safety thresholds. It can therefore be concluded that the calculated Excess Lifetime Cancer Risk suggests a low probability of cancer development among residents in most parts of the study area. As a result, the area can be considered radiologically safe.

Keywords Natural radionuclides, Radiometric, Radiological hazard indices, Fractured zone

1 Introduction

Since natural radiation sources account for around 80% of human exposure [1–2], human exposure to naturally occurring radiations has gained research attention in the past 20 years [3]. The majority of naturally occurring radioactive materials come from both terrestrial and cosmic sources; however, the radioactive isotopes potassium-40,



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uranium-238, and thorium-232 are of terrestrial origin [4]. The Earth's crust contains these primary terrestrial source of ionising radiation, which decays and releases radiation. The concentration and presence of these radionuclides in the crust vary greatly depending on the local geological features [5].

Significant variations in the atmospheric and geological conditions of the surroundings can affect the background ionising radiation level, which is known to be higher in igneous rocks, such as granite rocks and lower in sedimentary rocks, such as phosphate and shale rocks. However, some shale and phosphate have high level of those radionuclides [6–7]. Radon gas which is a daughter of uranium, poses notable health risks, especially in regions underlain by fractured basement rocks, where subsurface conditions can lead to elevated concentrations [8]. The primary determinant of the danger of human exposure is the activity concentrations of naturally occurring radionuclides interacting with biological tissues which have gotten into the human body either by absorption, ingestion or inhalation [9–10].

Despite that there is no place on Earth where radioactivity is totally absent, areas where the soil contains naturally occurring radionuclides at levels higher than the maximum permitted exposure limit can be extremely dangerous and significantly affect the health of those who reside there [11–12]. Likewise fractures in rock can have a considerable impact on natural radionuclide migration by establishing preferential paths for water movement and radioactive transport [13]. Natural radionuclide exposure can result in damage and clinical symptoms such as chromosomal alteration, cancer induction, free radical production, bone necrosis, and radiation carcinogenesis [14]. One of the factors for radiation carcinogenesis and hence increased mortality rates would be the effect of radionuclide interaction with the body thereby having effect on the immune system [15].

Numerous researchers worldwide have shown interest in measuring the natural radioactivity in rocks or estimating the radiological hazard indices using ground survey [16–20] or aero-radiometric survey [21–26] for radionuclide concentration distribution in rocks, geothermal potential evaluation or geochemical studies. The results obtained support the fact that activity concentration of an area is heavily influenced by its geological characteristics, such as the type of parent rock, and the presence of fractures [27].

The Nupe Basin, an intracratonic sedimentary formation, was selected for this study because there is limited existing research on the spatial distribution of natural radionuclides and radiological indices in the region. Additionally, the area is characterized by a significant fault system that stretches from North-Central to South-Western Nigeria, which could potentially influence the migration of radionuclides [28]. This geological feature makes the basin a particularly relevant and important location for this type of investigation. Also, recent studies have identified certain parts of the Nupe Basin as potential zones for geothermal exploration, which could drive development in the region.

Therefore, it is important to assess the potential risks associated with radionuclide distribution, and understanding these risks will help inform government policies aimed at ensuring environmental safety, ultimately supporting Sustainable Development Goal 3: Good Health and Well-being. This research provides novel insight into the distribution of natural radionuclides by examining an understudied geological setting. Although natural background radiation has been widely investigated globally, limited research exists

for this specific geological formation. The radiological hazard indices of absorbed dose rate, annual effective dose and excess lifetime cancer risk were evaluated and the results were compared with the recommended safe limits to determine the level of radiological health implication.

1.1 Location and geology of the study area

The study area is located in the North-central part of Nigeria, within Latitude 9° 00' to 10° 00' N and Longitude 5° 30' to 6° 30' E (Fig. 2 and 3). It is an intracratonic structure with a northwest–southeast (NW–SE) trend. The basin is adjacent and approximately perpendicular to the primary axis of Nigeria's Benue Trough and Niger Delta Basin (Fig. 1). It forms the north-western extension of the Anambra Basin and is one of the inland basins in Nigeria that constitutes Cretaceous and rift basins in Central and West Africa [29]. It is a down-warped shallow depression full of fluvial and marine Campanian-Maastrichtian strata filled with mostly Santonian to Maastrichtian sediments of sandstones, siltstones, and superficial alluvial deposits [30]. The Nupe Basin's Upper Cretaceous strata and sedimentation are rich in ironstones. The oldest rocks exposed in the Nupe Basin are Maastrichtian (66–72 mega annum), however sedimentation may have begun earlier. The formation is poor in fossils, and its age has mostly been inferred by photo-geological association with the Anambra Basin's post-Santonian series [31]. According to interpretations of geophysical data, drill logs, and Landsat pictures, the basin is surrounded by a system of linear faults that trend NW –SE [32]. Reference [33] also reported that the Ifewara-zungeru fault which trends in the NNE-SSW direction is located within the research region. Figures 1, 2 and 3 shows the geological, lithological and location maps of the study area.

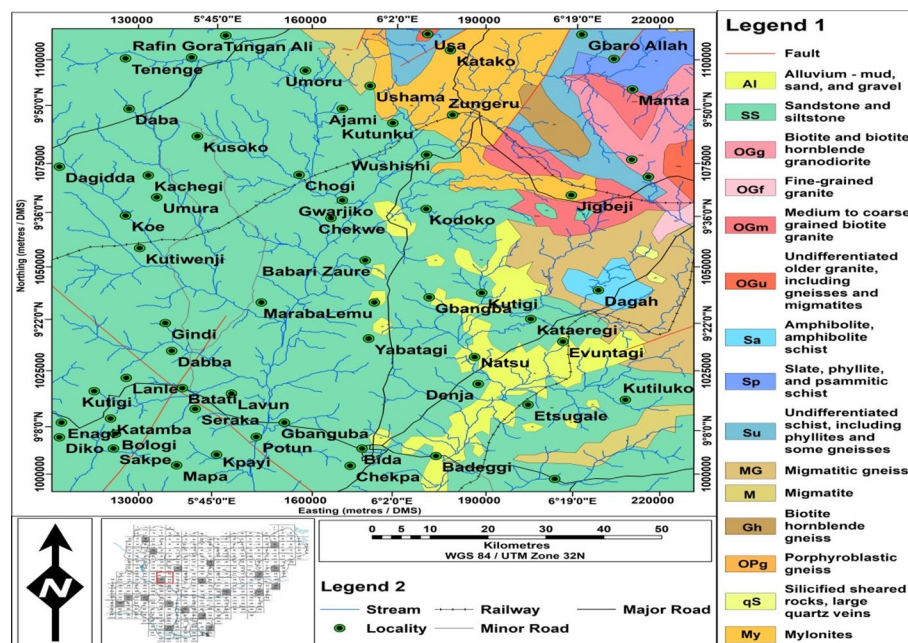


Fig. 2 Lithological map of the study area (Modified after [35])

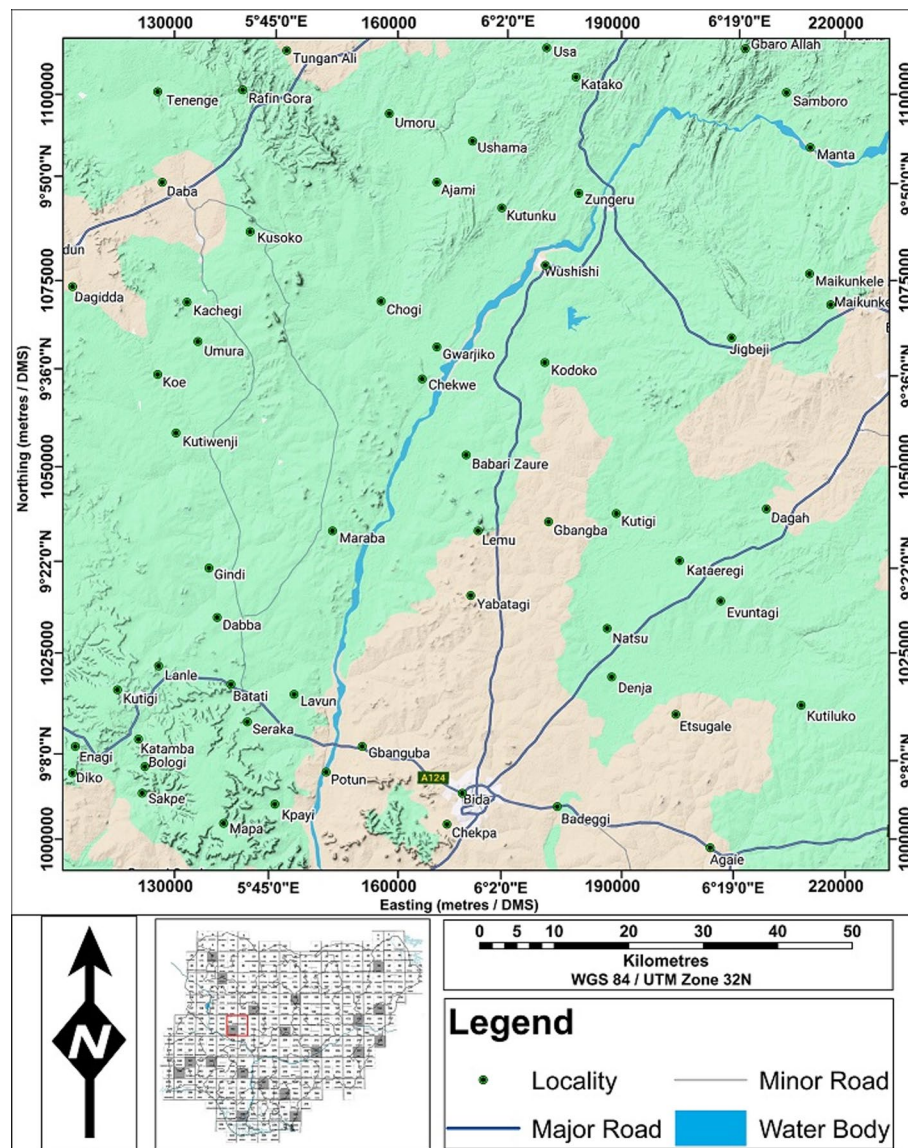


Fig. 3 Location map of the study area (Modified after [35])

1.2 Methodology

1.2.1 Data acquisition

The aero-radiometric data of parts of Nupe Basin, North central Nigeria comprising of Akerre (sheet 162), Zungeru (sheet 163), Egbako (sheet 183), and Bida (sheet 184) were collected from Nigeria Geological Survey Agency (NGSA). The aero-radiometric data which was acquired by Fugro Airborne Survey Limited, in the year 2009 was carried out using the 256-channels gamma-ray spectrometers (NaI “TI” crystals size of 2 x 2) [36]. The survey was conducted using fixed-wing aircraft flying at mean terrain clearance of 80 m, with 500 m line spacing and nominal tie line spacing of 2 km in the NE-SW direction. Scintillation detectors were used as counters with a data recording interval of 0.1 s, and an average flight elevation of about 100 m. The trends for the flight line and tie line were 135° and 45°, respectively. Contour maps were used to combine and display the acquired aerial gamma ray spectrometric data. Several corrections are usually performed to the data when utilising the airborne gamma survey to measure the

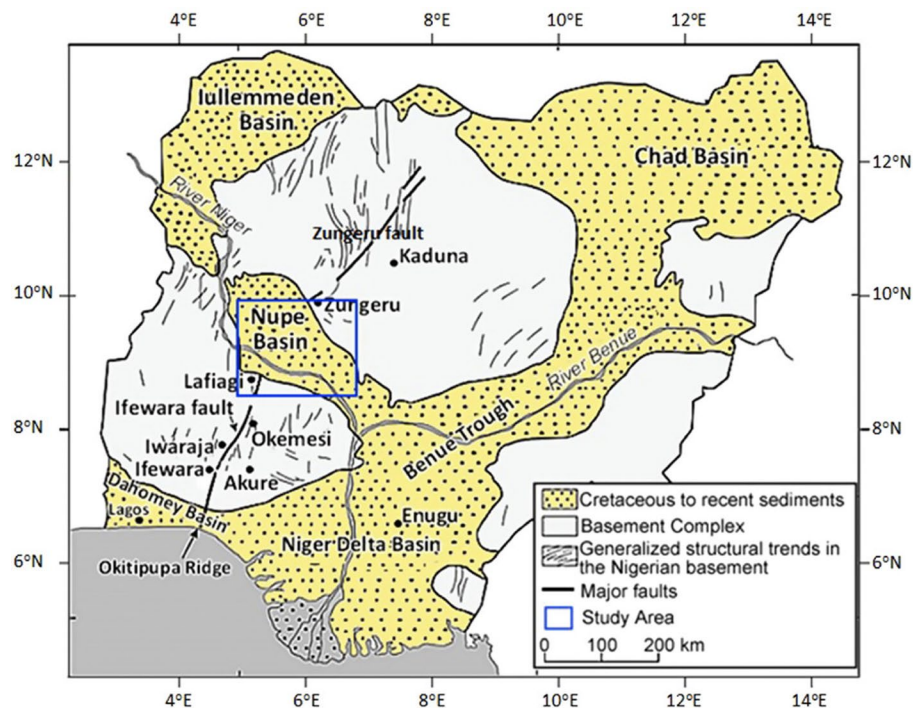


Fig. 1 Geological map of Nigeria showing the Nupe Basin (Modified after [34])

concentrations of uranium, thorium, and potassium in surface rocks. These corrections include background radiation from cosmic rays and aircraft contamination, variations from flying at different altitudes in relation to the ground, the uranium and potassium energy window's compton scattered gamma rays, and background and near-surface noises that could obscure important subsurface signals. With the use of a 1D non-linear filter, these inaccuracies were removed.

1.3 Aero-radiometric data processing and presentation

To estimate the apparent surface concentrations of potassium (K), uranium (U), and thorium (Th), the corrected radiometric data was processed using Oasis Montaj software. The concentrations of uranium and thorium are reported as equivalent values eU and eTh in parts per million (ppm), while potassium (K) concentrations are presented as equivalent ground concentrations in percent (%). Total gamma counts have been converted from micro-roentgens per hour ($\mu\text{R/h}$) to radiometric units of uranium (Ur). These corrected measurements provide estimates of the apparent surface concentrations of potassium (K), equivalent uranium (eU), and equivalent thorium (eTh), along with corresponding total count (TC) values. To estimate the radiological danger indices, the values were converted to Becquerel per kilogramme (Bq/Kg).

1.4 Evaluation of radiological hazard indices

Determining the radiological hazard parameters is the first step in evaluating the possible health concerns connected to radiation exposure for people. As for the biological impacts, the radiological and clinical consequences are directly tied to the absorbed dose rate (D), which is linked to the Annual Effective Dose (AED). The AED is likewise linked to the Excess Life Time Cancer Risk (ELCR),

- I. Absorbed Dose Rate (D): It is the energy that ionizing radiation deposits in a material per unit mass. It can be measured in joules per kilogram and expressed by gray (Gy), a similar S.I unit. The activity concentration of ^{238}U , ^{232}Th , and ^{40}K can be used to compute the absorbed dose rate D (nGy/h).

$$D \text{ (nGy/h)} = C_u A_u + C_{Th} A_{Th} + C_k A_k \quad (1)$$

where C_u , C_{Th} and C_k are the radionuclide concentrations in (Bqkg^{-1}) of Uranium, Thorium and Potassium respectively and A_u , A_{Th} , and A_k are the dose factors for C_u , C_{Th} and C_k . The values of A_u , A_{Th} , and A_k are 0.462, 0.604 and 0.042 respectively [37].

- II. Annual Effective Dose (AED): The International Commission on Radiation Protection established the minimum recommended limit to track and manage radiation exposure in humans. It is a metric used to compare the impact of radiation on human health. Compiling the effective dose over a 12-month period yields the Annual Effective Dose (AED). The conversion coefficient 0.7 SvGy^{-1} between the absorbed dose in air and the effective dose, as well as the outdoor occupancy factor, is always considered when estimating the Annual Effective Dose (AED) [38].

$$AED \text{ (mSv/y)} = D \times OF \times T \times CC \times 10^{-6} \quad (2)$$

where D is the measured absorbed dose rate in mSv/h, T is the total hours per year (8760 h), and OF is the outdoor occupancy factor which is 0.2 for outdoor because it is assumed that human spend 20% of their time outdoor and 80% indoors. CC is 0.7 Sv/Gy as conversion factor (CF) to convert the absorbed dose rate (D) in nGy/h to human effective dose equivalent [39–40].

- III. Excess Lifetime Cancer Risk (ELCR): The ELCR is a radiological risk assessment parameter that estimates the likelihood that a person would get cancer during the course of a lifetime exposure to low-dose radiation [7].

$$\text{Excess Lifetime Cancer Risk } ELCR = AED \times DL \times RF \quad (3)$$

where DL is the average duration of life which is 56.36 years [41] and RF is the cancer risk factor per Sievert (Sv^{-1}). According to the International Commission on Radiological Protection [42], the cancer risk factor for the general public exposed to low-dose background radiation that is thought to generate stochastic effects is 0.05 Sv^{-1} .

2 Results and discussion

2.1 Activity concentration of natural radionuclide

The results of the activity concentration of uranium, thorium and potassium in Bq/Kg are presented Table 1. Maps showing the spatial distribution of the activity concentration of uranium, thorium and potassium in the study area are presented in Figs. 4, 5 and 6 respectively.

Table 1 Activity concentration of natural radionuclides

S/N	Location	K (Bq/Kg)	Th (Bq/Kg)	U (Bq/Kg)
1	Tungan Ali	395.5 ± 2.12	99.75 ± 1.20	79.1 ± 0.34
2	Usa	108.3 ± 1.79	34.97 ± 1.05	28.6 ± 0.04
3	Gbaro Allah	499.5 ± 2.45	34.81 ± 2.02	26.2 ± 0.08
4	Tenenge	58.30 ± 0.85	30.74 ± 2.05	16.0 ± 0.20
5	Rafin Gora	32.30 ± 0.70	54.68 ± 1.59	58.0 ± 0.12
6	Umoru	341.4 ± 2.19	64.99 ± 0.59	42.9 ± 0.22
7	Ushama	336.2 ± 1.85	44.95 ± 0.65	35.3 ± 0.01
8	Samboro	457.2 ± 2.03	26.20 ± 0.78	3.7 ± 0.14
9	Katako	334.8 ± 1.70	34.91 ± 0.26	15.4 ± 0.26
10	Manta	1323.5 ± 3.00	107.98 ± 1.55	39.9 ± 0.18
11	Daba	33.90 ± 0.20	32.17 ± 0.05	28.2 ± 0.21
12	Ajami	208.8 ± 1.54	47.23 ± 0.07	52.2 ± 0.14
13	Zungeru	112.0 ± 0.09	17.80 ± 0.16	26.4 ± 0.04
14	Kusoko	51.50 ± 0.35	30.04 ± 0.30	17.5 ± 0.15
15	Kutunku	556.0 ± 1.55	47.21 ± 0.42	38.2 ± 0.19
16	Dagidda	29.00 ± 0.05	30.63 ± 0.19	23.4 ± 0.23
17	Kacheji	33.00 ± 0.04	42.87 ± 0.02	28.2 ± 0.06
18	Chogi	181.40 ± 0.54	38.06 ± 0.05	17.9 ± 0.05
19	Wushishi	44.40 ± 1.10	30.24 ± 0.01	15.1 ± 0.03
20	Maikunkele Hill	391.1 ± 0.90	27.24 ± 0.03	8.00 ± 0.08
21	Maikunkele	367.3 ± 0.70	40.02 ± 0.04	28.3 ± 0.16
22	Jigbeji	202.4 ± 1.55	20.57 ± 0.01	11.0 ± 0.05
23	Kodoko	293.7 ± 2.00	61.44 ± 0.35	41.6 ± 0.19
24	Gwarjiko	487.6 ± 2.32	65.79 ± 0.62	33.4 ± 0.17
25	Umura	34.80 ± 1.20	33.44 ± 0.04	14.1 ± 0.12
26	Koe	64.03 ± 1.86	29.59 ± 0.01	19.9 ± 0.08
27	Chekwe	108.8 ± 0.78	29.32 ± 0.09	13.9 ± 0.03
28	Kutiwenji	65.10 ± 0.05	44.80 ± 0.24	45.6 ± 0.05
29	Babari Zaure	234.2 ± 0.02	45.96 ± 0.20	30.1 ± 0.16
30	Maraba	53.30 ± 0.20	54.71 ± 0.03	51.1 ± 0.21
31	Lemu	71.50 ± 0.01	54.81 ± 0.06	50.4 ± 0.04
32	Gbangba	318.2 ± 1.57	58.25 ± 0.10	29.3 ± 0.01
33	Kutigi	316.9 ± 1.24	71.45 ± 0.12	33.5 ± 0.09
34	Dagah	188.2 ± 0.99	22.55 ± 0.03	12.3 ± 0.03
35	Kataeregi	148.3 ± 0.83	46.79 ± 0.05	30.3 ± 0.10
36	Gindi	68.00 ± 1.01	35.66 ± 0.02	26.7 ± 0.02
37	Dabba	44.8 ± 0.34	41.86 ± 0.41	28.4 ± 0.05
38	Yabatagi	51.5 ± 0.09	64.16 ± 0.32	52.3 ± 0.13
39	Evuntagi	94.0 ± 0.04	31.78 ± 0.23	17.4 ± 0.03
40	Natsu	381.3 ± 2.02	55.27 ± 0.64	29.8 ± 0.18
41	Denja	139.2 ± 1.17	44.76 ± 0.01	25.3 ± 0.09
42	Kutiluko	59.6 ± 0.04	27.69 ± 0.06	20.5 ± 0.14
43	Etsugale	262.0 ± 0.03	46.37 ± 0.04	24.4 ± 0.21
44	Agai	386.6 ± 1.57	97.89 ± 1.10	57.3 ± 0.22
45	Badeggi	121.3 ± 0.32	73.88 ± 0.92	57.0 ± 0.12
46	Bida	35.30 ± 0.25	56.83 ± 0.74	39.5 ± 0.17
47	Chekpa	41.10 ± 0.05	49.84 ± 0.15	39.1 ± 0.21
48	Lanle	36.8 ± 0.34	58.33 ± 0.17	33.7 ± 0.32
49	Kutigi	37.0 ± 0.07	77.62 ± 0.16	104.9 ± 0.25
50	Batati	27.0 ± 0.01	66.08 ± 0.11	64.3 ± 0.23
51	Lavun	42.5 ± 0.05	45.90 ± 0.04	31.9 ± 0.03
52	Seraka	52.4 ± 0.10	41.29 ± 0.40	36.5 ± 0.05
53	Katamba	49.0 ± 0.20	66.34 ± 0.30	48.0 ± 0.08

Table 1 (continued)

S/N	Location	K (Bq/Kg)	Th (Bq/Kg)	U (Bq/Kg)
54	Enagi	127.9±0.06	54.62±0.35	38.0±0.04
55	Diko	79.3±0.08	64.56±0.62	73.7±0.06
56	Bologi	58.6±1.20	54.18±0.49	39.2±0.16
57	Sakpe	41.7±1.30	44.48±0.03	32.6±0.14
58	Mapa	36.2±0.25	55.22±0.06	55.6±0.04
59	Kpayi	55.8±0.08	65.89±0.93	62.1±0.05
60	Potun	35.9±0.02	48.37±0.01	37.3±0.12
61	Gbanguba	129.6±1.05	55.59±0.72	31.9±0.17
	Maximum	1323.5±3.00	107.98±1.55	104.9±0.25
	Minimum	27.0±0.01	17.80±0.16	3.7±0.14
	Mean	179.9±0.21	48.89±0.15	35.3±0.07
	Standard Deviation	209.5±0.42	18.74±0.12	18.6±0.04

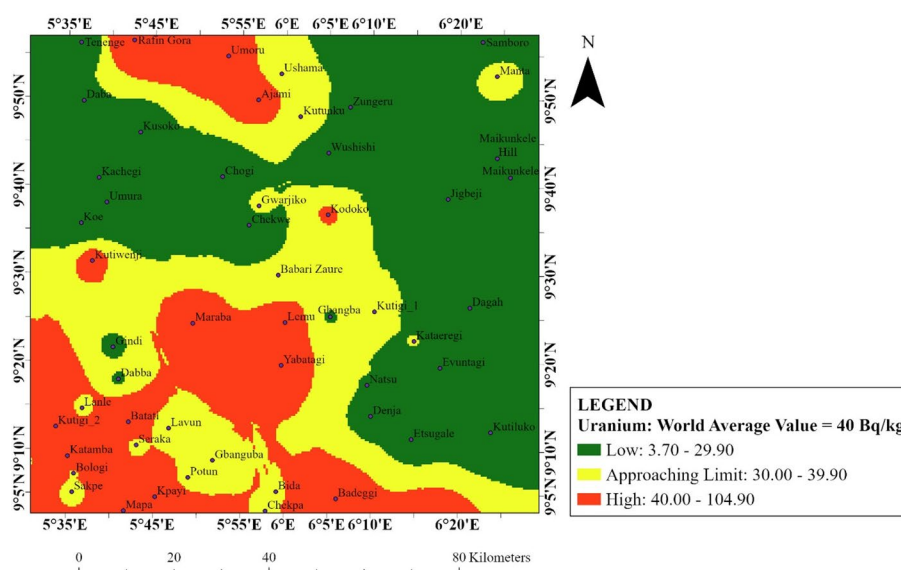


Fig. 4 Distribution of uranium concentration across the study area

Figures 4 and 5, and 6 revealed the concentration of uranium ranging from 3.70 ± 0.14 Bq/Kg at Samboro to 104.9 ± 0.25 Bq/Kg at Kutigi_2 with a mean and standard deviation of 35.3 ± 0.07 and 209.5 ± 0.42 Bq/Kg respectively. The concentration of thorium varies from 17.80 ± 0.16 Bq/Kg at Zungeru to 107.98 ± 1.55 Bq/Kg at Manta with a mean and standard deviation of 48.88 ± 0.15 and 18.74 ± 0.12 Bq/Kg respectively. The concentration of potassium varies from 27.0 ± 0.01 Bq/Kg at Batati to 1323.5 ± 3.00 Bq/Kg at Manta with a mean and standard deviation of 179.9 ± 0.21 and 18.6 ± 0.04 Bq/Kg respectively. The radionuclide concentrations are represented by green for values below, yellow for values approaching, and red for values above the world average value. High concentration of uranium which exceed the world average of value of 40 Bq/Kg [3] can be observed in the North (Tungan Ali, Umoru, Rafin Gora, Ajami), Southwest (Kutigi_2, Enagi, Diko, Bologi, Katamba), South (Mapa, Bologi, Kpayi, Badeggi, Agaie, Maraba) and environ. High concentration of thorium which also exceed the world average value of 40 Bq/Kg [3] can as well be observed in the North (Tungan Ali, Ajami, Umoru, Rafin Gora, Ushama), Northeast (Manta), Southwest (Maraba, Yabatagi, Kodoko, Kutigi_2, Enagi, Diko, Bologi, Mapa, Kpayi), Southeast (Badeggi, Agaie) and environ. The concentration

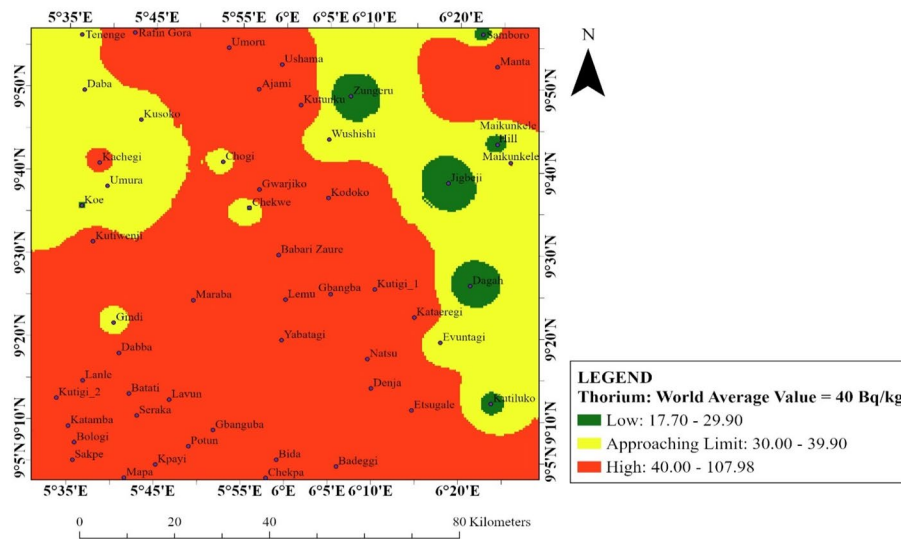


Fig. 5 Distribution of thorium concentration across the study area

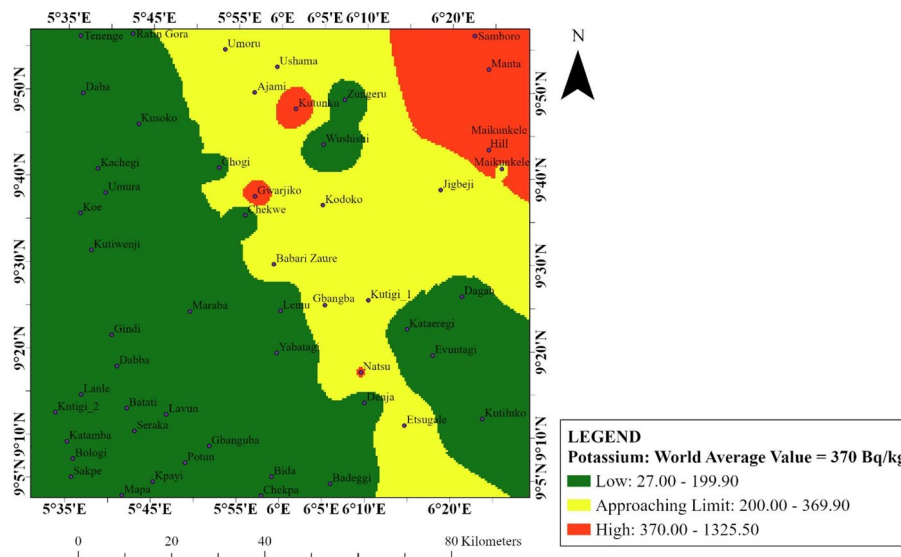


Fig. 6 Distribution of potassium concentration across the study area

of potassium in the Northeast (Gboro Allah, Samboro, Manta, Maikunkele Hill), North (Kutunku) and South (Agaie) likewise exceeds the world average value of 370 Bq/Kg [3]. While the mean value of uranium and potassium across the entire location does not exceed the world average value, the mean value of thorium does. However, residents may be at risk in areas with significant concentrations of naturally occurring radionuclides. These results correspond with what was obtained by [21] and [43] while it is slightly higher than that obtained by [44].

The results correlates with that obtained by [21, 43], and [44] while it is slightly higher than that obtained by [45]. According to [44], the concentration of uranium, thorium and potassium in Fileita Nubian sandstone characterized by Timsah fault zone is 32 ± 13 , 29.6 ± 12.2 , and 132.6 ± 86.4 Bq/Kg respectively.

2.2 Radiological hazard indices

Table 2; Figs. 7, 8 and 9 showed the estimated radiological hazard parameters of the study area.

Absorbed Dose Rate (D): The result of the absorbed dose rate as recorded in Table 2; Fig. 7 shows the amount of radiation deposit in materials per unit mass around the environment. Green, yellow and red colour represents areas with low, intermediate and high values respectively. The estimated value of the absorbed dose rate D ranges from 26.2 ± 0.01 nGy/h at Jigbeji to 139.24 ± 0.04 nGy/h at Manta with an average and standard deviation value of 53.38 ± 0.18 nGy/h and 22.28 ± 0.03 respectively. High values were observed in regions around Tungan Ali, Umoru, Rafin Gora, Gbangba, Yabatagi, lemu, Enagi, Diko, Badeggi, Agaie and environ. This region coincides with the areas where high concentration of uranium and thorium were recorded. It was observed that the average value of D is lower than the world weighted average value of 59.00 nGy/h according to [3], However, 4 locations (Kutigi_2, Tungan Ali, Manta, and Agaie) have the value of D greater than the recommended safe limit of 84.0 nGy/h as stated by [46–47] for outdoor radiation exposure. In general, the average value of D in the study area is lesser than the world weighted average and the recommended safe limit. However, the amount of absorbed dose rate in Kutigi_2, Tungan Ali, Manta, and Agaie may expose residents to health hazard.

Annual Effective Dose Equivalent (AED): The calculated AED as shown in Table 2; Fig. 5b shows values ranging from $3.19\text{E-}2 \pm 0.8\text{E-}2$ mSv/y at Jigbeji to $1.71\text{E-}1 \pm 0.4\text{E-}2$ mSv/y at Manta with a mean and standard deviation of $0.065 \pm 1.2\text{E-}2$ mSv/y and $2.7\text{E-}2 \pm 0.1\text{E-}2$ respectively. Green, yellow and red colour represents areas with low, intermediate and high values respectively. It can be observed that the mean value and the values across all locations are lesser than the world weighted average of 0.5 mSv/y [3] and the recommended safe limit of 1 mSv/y as recorded by [46–47].

Excess Lifetime Cancer Risk (ELCR): The computation of the ELCR which is a radiological risk assessment parameter, which estimates the likelihood that a person would get cancer during the course of a lifetime exposure to low-dose radiation, is depicted in green, yellow and red colour (Fig. 9). It can be observed that the values range from $0.89\text{E-}4 \pm 0.1\text{E-}4$ at Jigbeji to $4.81\text{E-}4 \pm 0.5\text{E-}4$ at Manta, with a mean and standard deviation of $1.85\text{E-}4 \pm 0.2\text{E-}4$ and $0.76 \pm 0.15\text{E-}4$ respectively. The mean of the ELCR, $1.85\text{E-}4 \pm 0.2\text{E-}4$ does not exceed the world average value of $1.45\text{E-}3$ [39] and the recommended safe limit of $3.75\text{E-}3$ [48]. However, Tungan Ali and Manta has their ELCR values higher than the recommended safe limit.

The results obtained is in agreement with [44], who stated that the mean of absorbed dose, the annual effective dose equivalent, and excess life time cancer risk are lower than the world wide mean.

3 Conclusion and recommendation

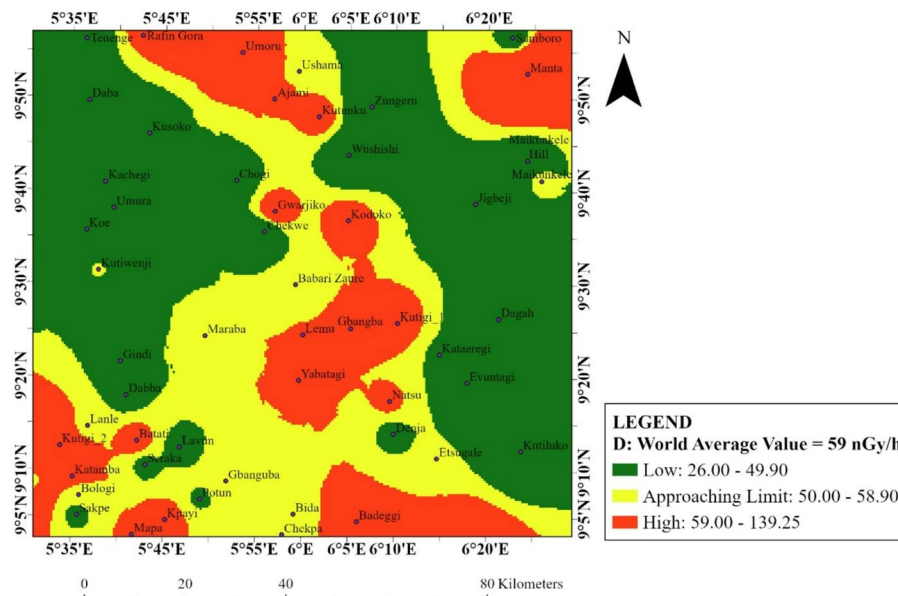
This study measured activity concentration of natural radionuclides (^{238}U , ^{232}Th , and ^{40}K) of some parts of Nupe basin, North central Nigeria, and the measured activity concentrations were used to determine the extent of radiation exposure of the general public. The mean concentration of ^{238}U and ^{40}K were found to be lower than the world average limit of 40 Bq/Kg and 370 Bq/Kg respectively as stated by [3] while the mean concentration of thorium exceeds the world average limit of 40 Bq/Kg. Some few locations

Table 2 Evaluation of radiological hazard indices

S/N	LOCATION	ABSORBED DOSE RATE (nGy/h)	ANNUAL EFFECTIVE DOSE (mSv/y)	EXCESS LIFE-TIME CANCER RISK
1	Tungan Ali	113.4±0.15	1.39E-1±1.0E-2	3.92E-4±1.0E-4
2	Usa	38.88±0.02	5.60E-2±0.5E-2	1.34E-4±0.2E-4
3	Gbaro Allah	54.11±0.01	6.60E-2±0.2E-2	1.87E-4±0.5E-4
4	Tenenge	28.41±0.11	3.50E-2±0.6E-2	9.82E-5±3.4E-4
5	Rafin Gora	61.18±0.10	7.50E-2±1.2E-2	2.11E-4±0.8E-4
6	Umoru	73.39±0.13	9.00E-2±1.4E-2	2.54E-4±0.4E-4
7	Ushama	57.57±0.09	7.06E-2±2.4E-2	1.99E-4±0.3E-4
8	Samboro	36.73±0.13	4.50E-2±0.9E-2	1.27E-4±0.4E-4
9	Katako	42.28±0.12	5.18E-2±1.2E-2	1.46E-4±0.1E-4
10	Manta	139.25±0.17	1.71E-1±0.4E-2	4.81E-4±0.5E-4
11	Daba	33.87±0.04	4.15E-2±0.8E-2	1.17E-4±0.3E-4
12	Ajami	61.43±0.01	7.53E-2±3.2E-2	2.12E-4±1.2E-4
13	Zungeru	27.63±0.05	3.39E-2±0.4E-2	9.55E-5±2.3E-4
14	Kusoko	28.39±0.14	3.48E-2±0.8E-2	9.81E-5±4.5E-4
15	Kutunku	69.52±0.09	8.53E-2±4.4E-2	2.40E-4±0.7E-4
16	Dagidda	30.55±0.12	3.75E-2±0.8E-2	1.06E-4±0.4E-4
17	Kachegei	40.29±0.03	4.94E-2±0.2E-2	1.39E-4±0.3E-4
18	Chogi	38.88±0.06	4.77E-2±1.3E-2	1.34E-4±0.1E-4
19	Wushishi	27.11±0.17	3.33E-2±0.3E-2	9.37E-5±0.9E-4
20	Maikunkele Hill	36.57±0.05	4.48E-2±0.5E-2	1.26E-4±0.8E-4
21	Maikunkele	52.69±0.14	6.46E-2±1.7E-2	1.82E-4±0.2E-4
22	Jigbeji	26.02±0.01	3.19E-2±0.8E-2	0.89E-4±0.1E-4
23	Kodoko	68.65±0.04	8.42E-2±1.9E-2	2.37E-4±1.0E-4
24	Gwarjiko	75.67±0.10	9.28E-2±3.9E-2	2.62E-4±1.2E-4
25	Umura	28.18±0.16	3.46E-2±0.4E-2	9.74E-5±3.7E-4
26	Koe	29.75±0.09	3.65E-2±0.1E-2	1.03E-4±0.8E-4
27	Chekwe	28.72±0.12	3.52E-2±0.6E-2	9.92E-5±2.8E-4
28	Kutiwenji	50.82±0.07	6.23E-2±2.3E-2	1.76E-4±0.9E-4
29	Babari Zaure	51.52±0.19	6.32E-2±1.8E-2	1.78E-4±0.3E-4
30	Maraba	58.90±0.13	7.22E-2±2.0E-2	2.04E-4±0.5E-4
31	Lemu	59.38±0.08	7.28E-2±2.8E-2	2.05E-4±0.2E-4
32	Gbangba	62.09±0.13	7.61E-2±1.5E-2	2.15E-4±0.7E-4
33	Kutigi_1	71.93±0.17	8.82E-2±3.4E-2	2.49E-4±0.3E-4
34	Dagah	27.19±0.04	3.34E-2±0.5E-2	9.40E-5±2.6E-4
35	Kataeregi	48.49±0.05	5.95E-2±1.6E-2	1.68E-4±0.1E-4
36	Gindi	36.73±0.06	4.50E-2±1.6E-2	1.27E-4±0.4E-4
37	Dabba	40.29±0.10	4.94E-2±0.3E-2	1.39E-4±0.6E-4
38	Yabatagi	65.09±0.07	7.98E-2±3.1E-2	2.25E-4±1.1E-4
39	Evuntagi	31.17±0.03	3.82E-2±1.1E-2	1.08E-4±0.2E-4
40	Natsu	63.16±0.09	7.75E-2±1.2E-2	2.18E-4±0.4E-4
41	Denja	44.58±0.18	5.47E-2±1.6E-2	1.54E-4±0.5E-4
42	Kutiluko	28.72±0.04	3.52E-2±0.4E-2	9.92E-5±3.9E-4
43	Etsugale	50.28±0.03	6.17E-2±2.4E-2	1.74E-4±0.7E-4
44	Agale	101.83±0.19	1.25E-1±0.2E-2	3.52E-4±0.8E-4
45	Badeggi	76.07±0.04	9.33E-2±2.5E-2	2.63E-4±0.6E-4
46	Bida	54.04±0.02	6.63E-2±1.8E-2	1.87E-4±0.2E-4
47	Chekpa	49.91±0.12	6.12E-2±2.0E-2	1.73E-4±0.1E-4
48	Lanle	52.35±0.21	6.42E-2±2.4E-2	1.81E-4±0.3E-4
49	Kutigi_2	96.88±0.05	1.19E-1±0.6E-2	3.35E-4±0.9E-4
50	Batati	70.78±0.04	8.68E-2±1.4E-2	2.45E-4±1.0E-4
51	Lavun	44.25±0.10	5.43E-2±1.8E-2	1.53E-4±0.3E-4
52	Seraka	44.01±0.11	5.40E-2±0.4E-2	1.52E-4±0.1E-4

Table 2 (continued)

S/N	LOCATION	ABSORBED DOSE RATE (nGy/h)	ANNUAL EFFECTIVE DOSE (mSv/y)	EXCESS LIFE-TIME CANCER RISK
53	Katamba	64.32±0.08	7.89E-2±2.3E-2	2.22E-4±0.4E-4
54	Enagi	55.93±0.01	6.86E-2±2.3E-2	1.93E-4±0.6E-4
55	Diko	76.37±0.22	9.37E-2±3.4E-2	2.64E-4±1.2E-4
56	Bologi	53.27±0.12	6.53E-2±1.4E-2	1.84E-4±0.5E-4
57	Sakpe	43.66±0.09	5.35E-2±1.3E-2	1.51E-4±0.3E-4
58	Mapa	60.56±0.13	7.43E-2±3.2E-2	2.09E-4±0.7E-4
59	Kpayi	70.83±0.05	8.69E-2±2.8E-2	2.45E-4±0.8E-4
60	Potun	47.94±0.06	5.88E-2±1.8E-2	1.66E-4±0.3E-4
61	Gbanguba	53.76±0.03	6.59E-2±1.6E-2	1.86E-4±0.6E-4
Maximum		139.25±0.04	1.71E-1±0.4E-2	4.81E-4±0.5E-4
Minimum		26.02±0.01	3.19E-2±0.8E-2	0.89E-4±0.1E-4
Mean		53.38±0.18	6.55E-2±1.2E-2	1.85E-4±0.2E-4
Standard deviation		22.28±0.03	2.7E-2±0.1E-2	0.76E-4±0.15E-4

**Fig. 7** Map of Absorbed dose rate (D)

were observed to have high concentration of the natural radionuclides. The absorption of these elements in those locations may expose residents to health hazards.

Further evaluation of the radiological hazard indices shows that the mean values of the absorbed dose rate (53.38 ± 0.18 nGy/h), annual effective dose (0.065 ± 0.02 mSv/y), and excess lifetime cancer risk at duration of life of 56.36 years ($1.85E-4 \pm 0.2E-4$) falls below the recommended safe limits. However, the ELCR of Tungan Ali and Manta is greater than the recommended safe limit. Therefore, the probability of developing cancer in these two locations is high.

Generally, the study area is considered to be radiologically safe and values of the calculated excess lifetime cancer risk indicate that the probability of developing cancer by residents of the study area is low. Although the aero-radiometric method used in this study enabled coverage of a large area, it lacks some details that are provided by ground-based

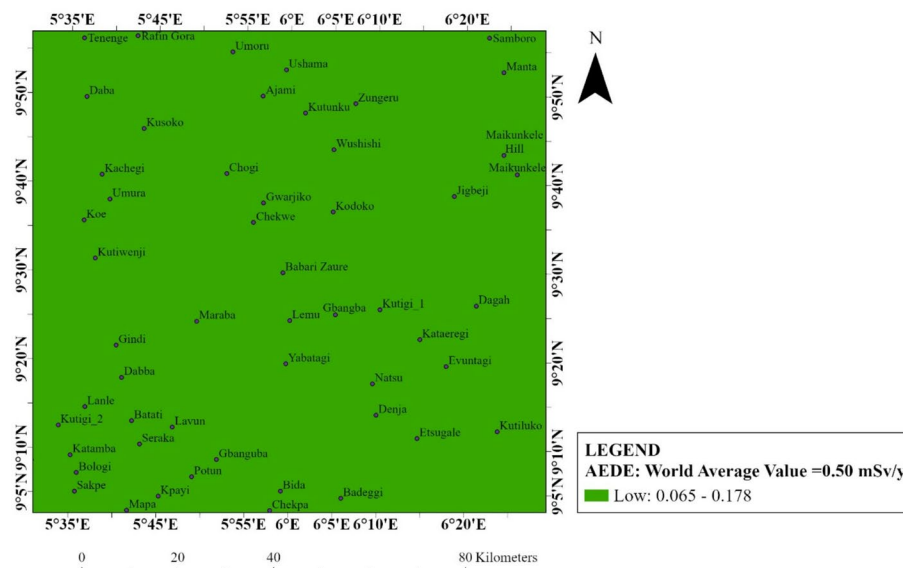


Fig. 8 Map of Annual effective dose equivalent

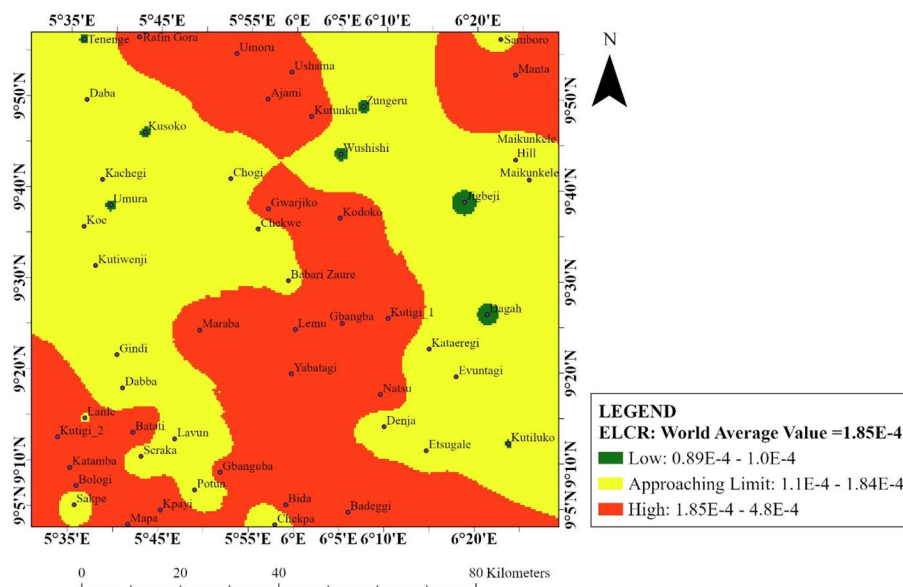


Fig. 9 Map of Excess life-time cancer risk

radiometric surveys. Therefore, continuous ground-based measurements are recommended to accurately assess radiation exposure and ensure it remains as low as reasonably achievable.

Author contributions

L.A. Sunmonu and E.A. Oni suggested the concept. H.I. Adewumi acquired the data from NGS.A.O.P. Oladejo suggested the methodology. S.A. Salaudeen and T.A. Olajide carried out the analysis. T.A. Olajide and G.B. Egbeyale interpreted the results. T.A. Olajide wrote the original manuscript. K.O. Suleman and A.A. Owajori contributed to the funding. O.P. Oyero reviewed and edited the manuscript. E.A. Oni supervised the project.

Funding

This research received no external funding and was carried out solely through the personal efforts of the authors.

Data availability

The data that support the findings of this study are available from Nigeria Geological Survey Agency [NGSA] but restrictions apply to the availability of these data, which were used under request for the current study.

Declarations

Ethics approval and consent to participate

This study did not involve any research conducted on human participants or animal subjects. As such, ethical approval was not required in accordance with the institutional and national guidelines. This study does not involve human participants, hence consent to participate is not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 4 August 2025 / Accepted: 3 October 2025

Published online: 07 October 2025

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