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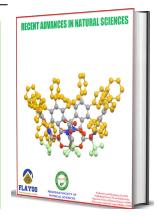

Assessment of radionuclide distribution and associated radiological hazards of soils in Mayo-Belwa, Adamawa state

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ABSTRACT

Mayo-Belwa Local Government Area has been reported to have deposits of Uranium; hence this study was carried out to measure radionuclide activities in Mayo-Belwa soils and to monitor their potential impact on human health. Soils from a depth of 10 cm were collected from each location, using CANBERA NaI (Tl) detector, the activity concentration of radionuclides of 10 soil samples was measured. The radionuclide concentration ranged between 72.7069 - 116.8504 $Bq.kg^{-1}$ for ^{238}U (measured by ^{226}Ra activity), 148.9168 -981.4994 $Bq.kg^{-1}$ for ^{40}K and 22.3332 - 108.5203 $Bq.kg^{-1}$for ^{232}Th. The gamma absorbed dose rate, annual effective dose rate, ranged between 61.3932-138.1076 $nGyh^{-1}$, 0.0830 - 0.211 $mSvy^{-1}$ with mean values of 95.1762 ± 21.5257 and 0.1216 ± 0.0359 respectively. The values obtained were compared with the reported data from UNSCEAR, 2000 and ICRP 2005. The excess lifetime cancer risk ranged between 0.00026-0.00061 with an average value of 8.44×10^{-4}. The gamma, internal and external hazard indices ranged between 0.4631-1.0975, 0.5969- 0.9978 and 0.3601-0.8087 respectively. However, dose rates recorded in all locations were above the 60 $nGyh^{-1}$ recommended limits by UNSCEAR 2000. Furthermore, Ganglare had a gamma index above 1, implying a significant radiation hazard. Also, the average excess lifetime cancer risk (ELCR) of 0.844×10^{-3} was relatively high ($t < 0.05$) and compared to the world average value of 0.29×10^{-3}. With the help of this study, we were able to establish the fundamental facts about the levels of radioactivity and related radiological dangers that exist in the soil of Mayo-Belwa Local Government.

1. INTRODUCTION

Over the years, the accumulation of radioactivity from radionuclides like ^{238}U, ^{232}Th, and ^{40}K as well as the decay by products found in soils and rocks have created a severe environmental risk to people as well as a number of animal species living in their natural habitats [1]. The most vulnerable are the offspring of the uranium and thorium series, specifically ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Po, and ^{228}Ra, ^{220R}n, ^{216}Po, ^{212}Pb, ^{212}Bi, and ^{212}Po respectively According to studies, just 4% of the total radiation that the

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earth's surface receives comes from artificial sources, while the majority—approximately 96%—comes from natural sources [2]. The weathering of granitic stones is one example of a terrestrial source of naturally occurring radionuclides that exhibit continuous activity [3–5]. As a result, radionuclides that are from rocks are naturally occurring [6]. The presence of certain accessory minerals that contain radionuclides, such as monazite, apatite, zircon, allanite, mica, sphene and feldspars, are what causes the high radiation levels [7–10] including oxides of manganese and hydroxide compounds, as well as colloidal iron [11–14]. Anthropogenic activities like nuclear weapon testing on a scheduled basis and unintentional emission from nuclear power facilities that emit radioactive substances into the environment are the main sources of artificial radioactivity. Additionally, it has been noted that too much phosphate fertilizer application in agricultural soils increases the amount of artificial radioactivity in the soil [15].

In addition, it has also been noted that industrial operations such as heavy metal mining, oil extraction, processing, and transport activities have increased functional concentration [16, 17]. These activities are prevalent within the study area. Hence, the need for routine assessment. Soils have been identified as potential repository for radionuclides and other types of contaminants [6]. Human health is at risk as a result of radioactive accumulation of radionuclide contaminants in terrestrial marine and marine settings. The bioavailability, uptake and transfer of these radionuclides in soils and various food chains are regulated by environmental factors including soil potential for redox clay-sized soil fraction, degree of weathering, number of contaminants, organic matter content, pH, temperature fluxes and precipitation [18, 19]. The physical and chemical properties of the ecosystem control these processes. However, the process by which radionuclides enter biological systems is comparable to how same systems absorb nutrients from food, water and soil [19]. Due to their elevated mobility and high solubility, radionuclides constitute an exposure concern when they are present in sediments [3, 4, 20, 21].

As an interface connecting other elements of the physical environment such as air and water soils retain radionuclides [22]. Through consumption, injection, and inhalation, radionuclides found in soil and sediments may be transferred to living things, including plants, animals and other environmental elements, where they can accumulate to dangerous amounts in the body [13, 23]. The production of gamma radiations from radioactive decay of the ^{238}U and ^{232}Th series, which includes ^{40}K, is a risk factor that can endanger the environment externally or internally through radon inhalation and ingestion by people and other living things [24–26]. Ionizing radiation from radioisotopes has been blamed for various chronic diseases' high rates such as lung and kidney malignancies, acute leucopoenia and anemia [27]. In addition, DNA damage from ionizing radiation can cause mutation [28]. Recently, studies on natural radionuclide origin and behavior [6, 29, 30], spatial distribution of soil, sediments, water and plants, [31–34], food crops [35] and soil effects of phosphorus ores and fertilizers [1, 36] have dominated many scientific fora. Reports of radionuclide enrichment in some sea foods and snails also exist [32, 37, 38]. Radioactive contaminants in soils have been identified and possible remediation strategies such as stabilization and chemical extraction techniques have been suggested. Research show that beach sediments and sands often used in building houses contain certain levels of naturally occurring radioactive materials resulting from primordial radionuclide of cosmic origin [39–41].

A study conducted by Ref. [42] in Niger state on determination of radiological hazard indices from surface soil to individuals in Angwan kawo gold mining site indicated that radioactivity and absorbed doses were below the ICRP recommended public dose limit of 1 $mSvy^{-1}$. Another study conducted by Ref. [43] shows that the radiological hazards from radionuclide concentration obtained in Northwestern Nigeria (Zamfara State) is greater than the admissible recommended limits and the world average. Mining activities have emerged as a prominent contributor to radiation exposure from naturally occurring radioactive materials (NORMs). Unfortunately, this has resulted in public exposure doses that are contrary to accepted radiation protection standards, thereby lacking justification [44]. Inadequate ventilation in mining operations could result in radiation levels surpassing established limits, leading to significantly higher incidence of lung cancer among both mining workers and the general public [45].

Measured concentration of radionuclides from mining sites either exceed or fall below the established baseline limits. This discrepancy is attributed to the varying mineral content and distinct geology found in different locations, resulting in natural radioactivity levels that differ from one place to another [46–48].

It is crucial to assess the public dose potentially resulting from radioactivity generated by mining activities. This estimation is essential to determine the probability of public exposure and to ensure public confidence that this exposure remains below the recommended dose limit of 1 $mSvy^{-1}$, as established by reputable organizations [44]. Therefore, this study was conducted in Mayo-Belwa to assess the levels of radionuclide activities and the associated radiological risk, This is necessary because sand and laterites obtained from these areas site is utilized as a construction material for residential, educational and commercial buildings.

2. MATERIALS AND METHODS

2.1. STUDY AREA

Mayo-Belwa is a Local Government Area of Adamawa State in Nigeria. It has a total land area of 1.768 km^2 and located between $8°3'N - 9°10'N$ and $11°50'E - 12°10'E$ with an estimated population of about 204200 people. It is located between Jada and Demsa local government areas of the state and shares boundary with Taraba State as shown in Figure 1. The majority of residents in Mayo-Belwa belong to the Chamba ethnic group and are active farmers. However, the presence of abundant natural resources has led to an increase in illegal mining activities, as many young people seek alternative sources of income.

2.2. SAMPLING COLLECTION AND PREPARATION

The Geiger Muller system was used to determine the count rate at every sample location considered in this study. The Garmin Etrex 20 Handheld Global Positioning System was used to determine the coordinate of each location where samples were collected. Background radiation in counts per minute was recorded for 20 locations. Sample locations were selected randomly from the table of background radiation to include the location with

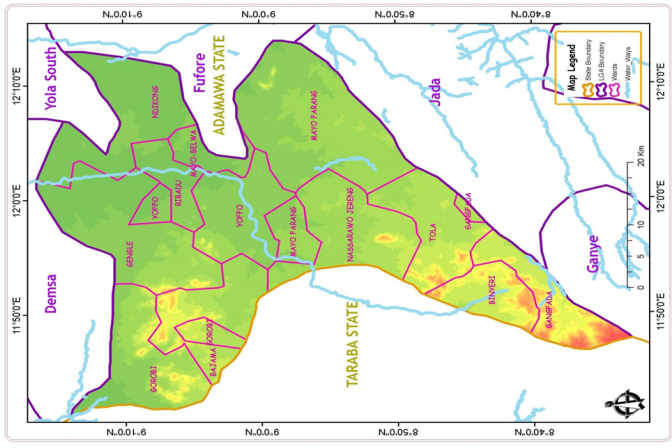

Figure 1. Settlement Map of Mayo-Belwa Local Government Area of Adamawa State

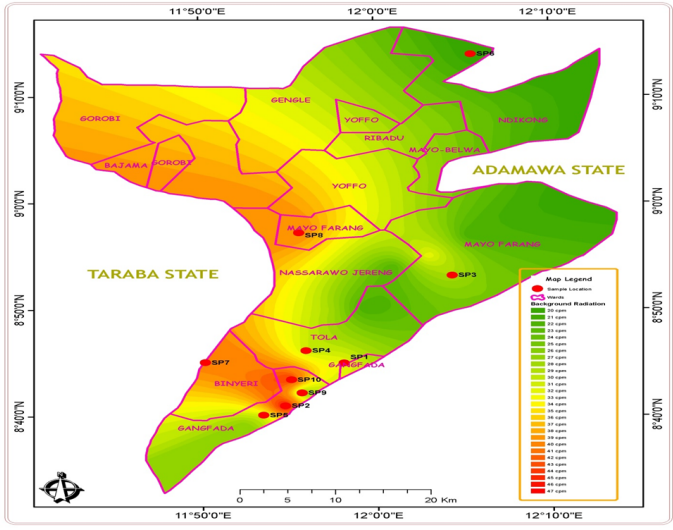

Figure 2. Background radiation contour map of Mayo-Belwa local government Area.

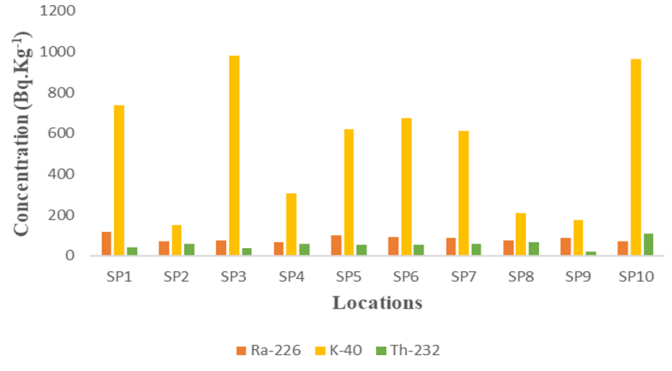

Figure 3. Radionuclide concentration from Mayo-Belwa Adamawa State grouped according to area.

minimum and maximum counts of gamma radiation. A 10 cm deep hand corer was used to collect soil samples. A total of ten (10) soil samples were collected and analyzed for radionuclide activity. Collected soil samples were dried and crushed to fine powder with a pulverized.

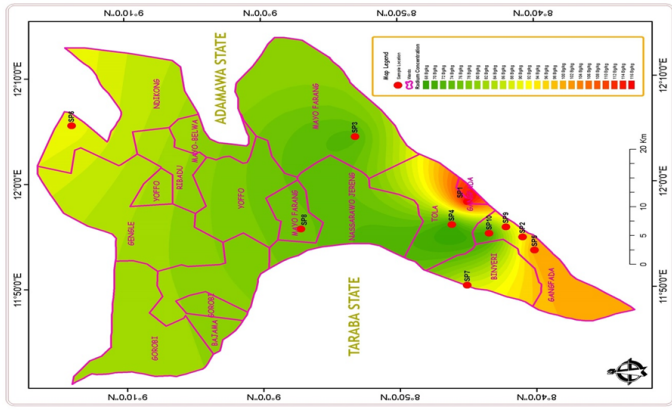

Figure 4. Radium (^{226}Ra) Activity Contour map for in Mayo-Belwa Local Government Area

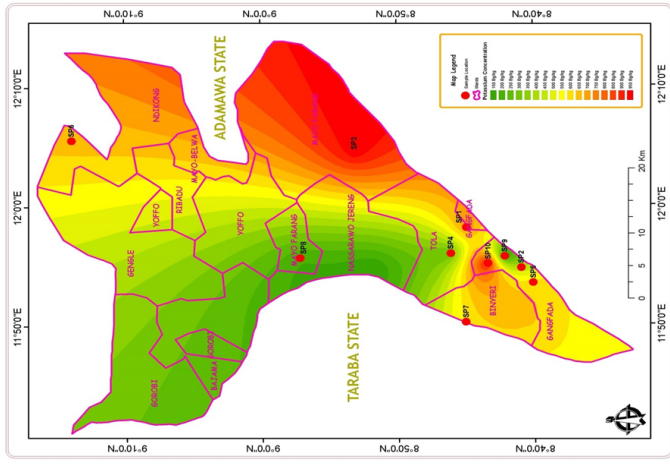

Figure 5. Potassium (^{40}K) Activity contour map of Mayo-Belwa Local Government Area

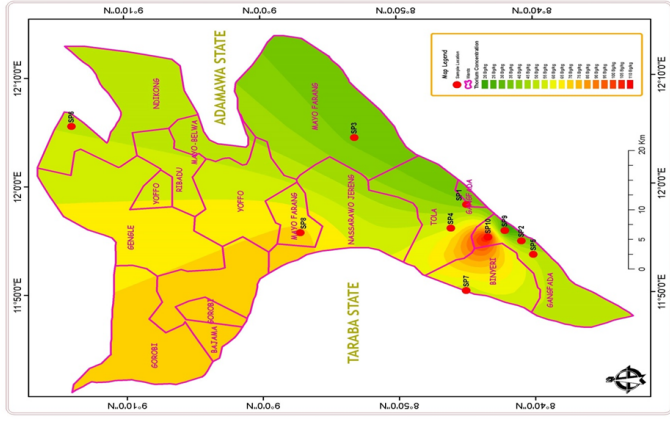

Figure 6. Thorium (^{232}Th) Activity contour map of Mayo-Belwa Local Government Area.

2.3. ANALYSIS OF SAMPLES

The Radionuclide analysis was carried out Center for energy research and training Zaria. Kaduna state Nigeria. A 76×76mm CANBERRA, Model 727 NaI (Tl) detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1 kilovolt external source. The

detector is enclosed in a 6 cm lead shield with cadmium and copper sheets. This arrangement is aimed at minimizing the effects of background and scattered radiation. Each soil sample was measured for 29000 seconds. The peak area of each energy in the spectrum was used to compute the activity concentrations in each sample using the following equation:

$$C(Bq.kg^{-1}) = C_n/C_{fk} \tag{1}$$

where C denote activity concentration of the radionuclides in the sample given in $Bq.kg^{-1}$, C_n represents count rate (counts per second) abd C_{fk} denotes C=calibration factor of the detecting system.

$$Count\ per\ second\ \ (cps) = Net\ Count/Live\ Count \tag{2}$$

2.4. STATISTICAL ANALYSIS

Baseline levels of metals in Mayo – Belwa soil samples were determined using Microsoft Excel version 12 (2007) for Windows. Descriptive statistics such as range, mean, and standard deviation were then calculated for the radionuclide levels in the soil samples.

3. THEORETICAL BACKGROUND

3.1. GAMMA ABSORBED DOSE RATE

The contribution of the natural radionuclides to the absorbed dose rate in air (D) depends on the concentration of the radionuclides in the soil. The dose can be calculated using absorbed dose rate conversion factors depending on the radionuclides in the soil. The conversion factors described by Ref. [54] were adopted and the gamma absorbed dose rates were calculated using the following formula:

$$D\left(nGyh^{-1}\right) = 0.462A_U + 0.604A_{Th} + 0.0417A_K, \tag{3}$$

where D is the dose rate at 1m above the ground and A_U, A_{Th}, and A_K are the activity concentrations $(Bq.kg^{-1})$ of ^{238}U, ^{232}Th, and ^{40}K, respectively, in the soil sample according to Ref. [55].

3.2. ANNUAL EFFECTIVE DOSE RATE

The gamma absorbed doses rate in $nGyh^{-1}$ were converted to annual effective dose in μSvy^{-1}, as proposed by Goran *et al.* [53]. The annual effective dose rate (AEDR) was calculated using the following equation:

$$AEDR\left(\mu Svy^{-1}\right) = D\left(nGyh^{-1}\right) \times 8760\left(hy^{-1}\right) \times 0.2 \times 0.7\left(SvGy^{-1}\right) \times 10^{-3}, \tag{4}$$

where D is the absorbed dose rate in air $(nGyh^{-1})$, 0.7 is the dose conversion factor $\left(SvGy^{-1}\right)$, 0.2 is the outdoor occupancy factor, and 8760 is the time conversion factor (hy^{-1}) according to Ref. [55].

3.3. INTERNAL HAZARD INDEX

The internal radiation index is the internal exposure due to ^{222}Rn and it short lived decay products. This was calculated using equation 5 and must be less than or equal to unity according to Refs. [49–52].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259.} + \frac{A_K}{4810} \leq 1. \tag{5}$$

3.4. GAMMA INDEX (I_γ)

This was adopted to check the possibility of application of building materials. The gamma index is calculated using the following formula according to Refs. [53].

$$I_\gamma = \frac{A\ (Ra)}{300} + \frac{A(Th)}{200} + \frac{A(K)}{3000} \leq 1. \tag{6}$$

3.5. EXTERNAL HAZARD INDEX

External hazard index is applied to reflect external exposure and it presents a single index that gives the gamma yield from different combinations of ^{226} Ra, ^{232}Th and ^{40}K in the sample. It is defined by the following equation according to Refs. [43, 49, 50, 52] as:

$$H_{ex} = \frac{A\ (Ra)}{370} + \frac{A(Th)}{259} + \frac{A(K)}{4810} \leq 1. \tag{7}$$

3.6. EXCESSIVE LIFETIME CANCER RISKS

This is the probability of developing cancer over a lifetime at a given exposure level. This was presented as a value representing the number of cancers expected in a given number of people on exposure to carcinogen at a given dose. ELCR was estimated using the equation

$$ELCR = AEDE \times DL \times RF \times 10^{-3}, \tag{8}$$

where AEDE is the annual effective dose equivalent, DL is the average duration of life (estimated 70) and RF the Risk factor (Sv) is 0.05 for public according to Ref. [51].

4. RESULTS AND DISCUSSION

4.1. BACKGROUND RADIATION

Figure 2 shows Geiger Muller background radiation of twenty (20) locations in Mayo-Belwa Local Government Area, Adamawa State. The radiation counts per minute ranged between 19 cpm to 48 cpm. Furthermore, the radiation counts were lower than 100 cpm warning radiation count.

4.2. ACTIVITY CONCENTRATION

According to results from radionuclide examination in Table 1, Figure 3 and Figure 4, the highest Radium activity 116.8504 $Bq.kg^{-1}$ was reported in SP1 while the lowest activity 68.6322 $Bq.kg^{-1}$ was reported in SP4 Also, the average radium activity value exceeded world average value recommended by Ref. [54]. The highest potassium activity 981.4994 $Bq.kg^{-1}$ was reported in SP3 while the least activity 148.9168 $Bq.kg^{-1}$ was reported in SP2 as seen in Table 1 and Figure 5. Four locations (SP2, SP9, SP8, and SP4) had potassium activity levels lower than world average value 370 $Bq.kg^{-1}$ while other locations had potassium activity levels higher than world average value by Ref. [54]. Hence, residents in these locations are prone to potassium poisoning. The highest value of thorium activity 108.5203 $Bq.kg^{-1}$ was reported in SP10 while the lowest activity 22.3332 $Bq.kg^{-1}$ was reported in SP9. Two locations (SP9 and SP3) had ^{232}Th activities lower than world average value 40 $Bq.kg^{-1}$ as stipulated in Ref. [54] and shown in Figure 6. The mean value of Radium activity, Potassium activity in this study were higher value than those from previous studies presented in Table 2 this could be attributed to uneven distribution of radionuclide in the soil. The radionuclide concentration contour maps of the study area Figures

Table 1. ^{226}Ra, ^{40}K, ^{232}Th activity concentration of samples

Location	^{226}Ra ($Bq.kg^{-1}$)	^{40}K($Bq.kg^{-1}$)	^{232}Th($Bq.kg^{-1}$)
SP1	116.8504 ± 6.5916	739.8649 ± 1.1369	41.2849 ± 2.9489
SP2	72.7069 ± 6.9112	148.9168 ± 0.9384	57.3663 ± 8.4143
SP3	73.1464 ± 6.3119	981.4994 ± 1.2709	38.0214 ± 8.4143
SP4	68.6322 ± 6.9511	304.6976 ± 1.3460	58.7818 ± 6.6449
SP5	101.6299 ± 7.9498	621.9970 ± 1.4157	54.4567 ± 7.5492
SP6	91.2832 ± 6.7913	675.9974 ± 0.7293	54.4567 ± 5.3867
SP7	89.1259 ± 6.8313	612.7735 ± 1.2387	56.3440 ± 8.9254
SP8	76.9016 ± 6.5117	209.4595 ± 0.1604	66.4097 ± 4.6396
SP9	87.6478 ± 8.5091	177.7134 ± 1.0296	22.3332 ± 3.3028
SP10	69.9505 ± 6.1122	965.0901 ± 1.1476	108.5203 ± 8.6108
Mean	84.7874 ± 15.6548	543.8010±315.3061	55.7975± 22.4945

Table 2. Comparison of results of present study with similar work

References	Country	^{226}Ra ($Bq.kg^{-1}$)	^{232}Th ($Bq.kg^{-1}$)	^{40}K ($Bq.kg^{-1}$)	*ELCR*	*D* $nGyh^{-1}$	*AEDR* $mSvy^{-1}$
Present Study	Nigeria	84.79 ± 15.66	55.80 ± 22.50	543.80 ± 315.31	0.0004	95.18 ± 21.53	0.12±.04
Esiole *et al.* [42]	Nigeria	53.94 ± 3.02	48.61 ± 2.06	314 ± 23.03	*	53.94 ± 2.84	*
Ademola *et al.* [56]	Nigeria	55.3 ± 1.2	26.4 ± 2.7	505.1 ± 7.1	*	66.3 ± 4.1	0.081 ± 5.0
Akpanowo *et al.* [43]	Nigeria	41.60 ± 11.06	151.15 ± 21.09	380.34 ± 116.41	0.00062	145 ± 26	*
Adewoyin *et al.* [57]	Nigeria	25.49 ±1.05	64.89 ±1.50	181.38 ± 2.22	*	61.68	*
Durusoy and Yildirim [55]	Turkey	24.5	51.8	344.9	*	56.9	0.069
UNSCEAR [54]	World Average	35	30	420	0.00029	60	0.07

*: Not included in the study

Table 3. Absorbed dose rate, annual effective dose rate, excess lifetime cancer risk, gamma index, internal and external hazard indices from the different locations. All values were obtained using formulas as previously stated.s

Locations	D $(nGyh)^{-1}$	AEDR $(mSvy)^{-1}$	ELCR	H_{in}	H_{ex}	I_γ
Tola	109.7316	0.1346	0.00047	0.9448	0.6290	0.8430
Gang Fada	74.4497	0.0913	0.00047	0. 6455	0.4489	0.5788
Balgare	94.6871	0.1161	0.00042	0.7462	0.5485	0.7611
Tola Jabu	79.9182	0.0980	0.00035	0.8872	0.4758	0.6242
Gajere	105.0855	0.1289	0.00046	0.8267	0.6126	0.8162
Gongoshi	103.2534	0.1266	0.00045	0.8442	0.5975	0.8019
Binyiri	100.7610	0.1235	0.00044	0.8267	0.5858	0.7830
Mayo Dembi	84.3745	0.1035	0.00037	0.7156	0.5078	0.6582
Gashifa	61.3932	0.0830	0.00026	0.5969	0.3601	0.4631
Ganglare	138.1076	0.2112	0.00062	0.9978	0.8087	1.0975
Mean	95.1762 ± 21.5257	0.1216±.0359	0.0004 ± .0001	0.8032 ±.1274	0.5575 ±.1219	0.7427 ±.1742

4, 5 and 6 show areas with highest activities in red colour, yellow colour represent areas with higher activity while areas with the lowest activities are in green colour.

4.3. RADIOLOGICAL RISK ASSESSMENT PARAMETERS

The absorbed dose rate in the soil samples in the area of study presented in Table 3 varied from 61.3932 $nGyh^{-1}$ (S9) to 138.1076 $nGyh^{-1}$ (S10) with an average value of 95.1762 $nGyh^{-1}$. The absorbed dose was slightly higher than Ref. [54] population weighted average value of 60 $nGyh^{-1}$. The annual effective dose rate in Table 3 was estimated to quantify the radiological risk of radionuclides in soil to the inhabitants and the results ranged between 0.0830 and 0.2112 $mSvy^{-1}$ with an average value of 0.1216 $mSvy^{-1}$ The average value of the AEDR was observed to be higher than the world recommended safe limit of $0.07mSvy^{-1}$ by an approximate factor of 2. The result of AEDR in the present study was much greater than values reported by in Ref. [56] (Table 2). The gamma index, internal and external hazard indices satisfied the criterion of unity in all locations except SP10 which recorded a gamma index of 1.0975 (Table 3) but the total average were below the values reported by Refs. [49–52] criterion corresponding to ≤. The Excess lifetime cancer risk ob-

tained ranged between 0.00026 and 0.00047 with average value of 0.0004±.0001. This value was greater than Ref. [54] world average value of 0.00029 (Table 2).

5. CONCLUSIONS

The maximum and minimum concentrations of radionuclides reported in this study varied for the three examined radionuclides across different locations within Mayo-Belwa local government area, Adamawa State. For each examined radionuclide, locations with the highest and lowest activity concentrations also had the highest and least counts per second (cps) respectively. The radium equivalent of the locations was lower than the recommended value which means their soil is suitable for agriculture and construction. Though the internal, external and most gamma indices were below the recommended value the gamma index of SP10 was above unity and this requires further investigation or remediation. The absorbed dose rate, annual effective dose rate and excess lifetime cancer risk were above the Ref. [54] recommended world average suggesting higher radionuclide activity concentration. Hence, adequate in-situ monitoring facilities should be employed to confirm risk level and ensure safety of residents of SP10.

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