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MEASUREMENT OF PRIMORDIAL RADIOACTIVITY FOR ASSESSMENT OF RADIOLOGICAL HAZARDS IN AGRICULTURAL SOIL IN BICHI AND NEIGHBORING COMMUNITIES IN KANO STATE, NIGERIA.

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Abstract

Farming, and other human activities, can enhance natural radioactivity in the soil. This has made measurements and monitoring of natural radionuclides in our farmlands and environment a necessity. 15 soil samples were collected from farmlands in Bichi town and four (4) neighboring communities: Danzabua; Chiromawa; Dan-Gwarzo and Tabari, for measurement of primordial radionuclides and assessment of radiological hazards using gamma-ray spectrometer coupled with Sodium-Iodide Scintillation detector. The activity concentrations, in BqKg^{-1}, of ^{40}K, ^{238}U and ^{232}Th in the study area ranged from: 412.34 – 749.46 (mean: 554.97 ± 27.77), 10.70 – 31.79 (mean:18.65 ± 2.00) and 6.50 – 18.00 (mean: 11.22 ± 0.65) respectively. The higher concentration of ^{40}K in the study area is due to the fact that ^{40}K is a macronutrient and the most abundant radionuclide in nature. The Radium equivalent activity, Ra_{eq}, external hazard index, H_{ex}, internal hazard index, H_{in} and gamma index Iγ of the farm soils in the study area ranged from: 63.18 – 95.42 (mean:77.43 BqKg^{-1}), 0.17 – 0.26 (mean:0.21), 0.21 – 0.32 (mean:0.26) and 0.25 – 0.38 (mean:0.30) accordingly. All the estimated values are less than their corresponding world average values. Also, the absorbed dose rate, D, annual gonad equivalent dose, AGED, annual effective dose rate, AEDR and excess lifetime cancer risk, ELCR, obtained in the study ranged from: 31.21 – 47.76 (mean:38.54 nGy.h^{-1}), 225.56 – 346.18 (mean:278.80 mSv.y^{-1}), 0.038 – 0.059 (mean:0.047 mSv.y^{-1}) and 0.087 x 10^{-3} – 0.133 x10^{-3} (mean:0.108 x 10^{-3}). The average values of D, AGED, AEDR and ELCR obtained in the study area were equally less than their corresponding world average values. Therefore, the soils in the study area posed no immediate threat or hazard to lives of farmers, population and consumers of plants grown in the area.

Keywords: Primordial radioactivity, Radiological hazards, Agricultural soil, Bichi, Kano State.

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Introduction

Natural radioactivity is common in rocks and soil that makes up our planet, in water and oceans, and, in our building materials and homes. There is no material on Earth that does not contain some amount of natural radioactivity. Over 60 radioactive elements can be found in nature, and are placed in three (3) general categories: Primordial (from before the creation of the Earth); Cosmo-genic (formed as a result of cosmic ray interactions); and Human produced (enhanced or formed due to human actions). Measurement of external gamma dose due to terrestrial sources is very important not only because of its contributions to the collective dose, but also because of variations of the individual dose related to the pathway. These doses depend on the concentrations of ^{236}U, ^{232}Th, their progenies and ^{40}K, present in rocks and soil, which in turns depend on the geology of the place (Malik, 2011; Quindos *et. al.*,1994). Human activities such as mining, farming, industrial activities, indiscriminate dumping of refuse/waste, as well as industrial and laboratory waste, studies have shown, have direct consequence on and can enhance the natural radioactivity of the environment (UNSCEAR, 2000). All soil everywhere in the world contains radionuclides to a greater or lesser extent. Typical soils (IA89a) contain approximately 300kBq/m^3 of ^{40}K to a depth of 20cm. By far, the largest source of natural radiation exposure comes from varying amounts of Uranium, Thorium and their progenies in the soil around the world. Soil plays major roles in the ecological balance, hydrological buffer, exploration and mining operations, agricultural processes and other sustainable development activities (industrial activities, energy needs fulfillment activities, etc.) for human survival (Ademola *et al*., 2014). Farming (or crop and animal production processes) remains one of the oldest and a major activity needed for survival, healthy living and sustenance of humans in the world. Soil has been consistently put into use by man in the cultivation of plants and rearing of animals for production of food for man's energy. Farming activities, clearing of bushes (or burning in some cases), making of ridges, application of manure/fertilizer, application of chemical (pesticides etc.) can enhance the background natural radioactivity in the soil and this is eventually taken up by the plant during growth and fruit production leading to intake by man. Many studies have been carried out by researchers on measurement of primordial/natural radioactivity for assessment of radiological hazards of soil use for cultivation of plants by man. Some of these studies include that of: Ademola, (2019); Tyovendar *et al*., (2022); Azionu *et al*., (2021); Adeleke *et al*., (2021); Ocheje *et al*., (2021); Avwiri *et al*., (2021); Alausa *et al*., (2020); Alausa, (2020); Adesiji & Ademola, (2019) and many other scholars too numerous to mention. It has, therefore, become a thing of necessity to measure the activity concentrations of primordial radioactivity in Bichi and its neighboring communities, where a significant percentage of the population rely on plants grown locally for food, so as to assess the hazard indices and/or radiation exposure indicators of the farm lands, their contribution to collective dose, fitness for plant cultivation and hence safety for people living in the communities. Since there is dearth of record about this in the area selected for this study.

Materials and Method

Map of the Area of Study:

Below is the Map of Kano State showing Bichi Local Government Area, the study area of this research.

Map of Kano State showing Bichi Local Government Area

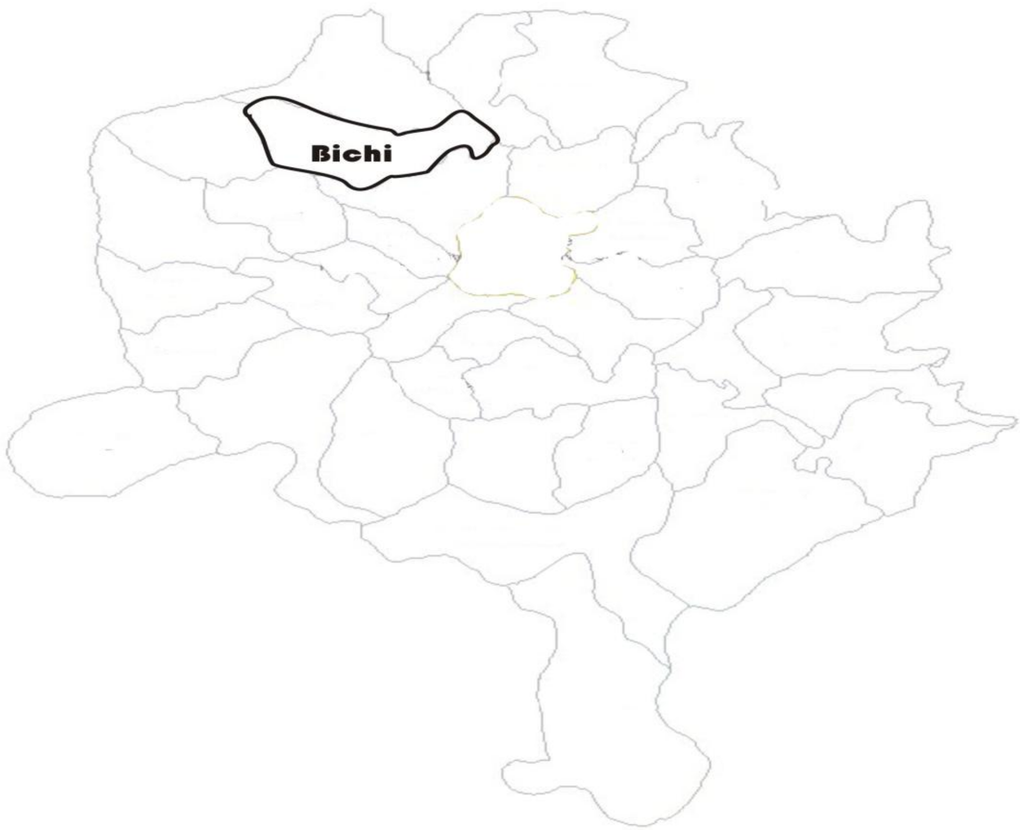

Figure 1: Map of Kano showing the Study area.

The Study Area

Bichi is one of the 44 Local Government Areas (and headquarter of Bichi Emirate Council) of Kano State, Nigeria. Its headquarters are in the town of Bichi on A9 highway. Bichi is founded by Danejawa, the white herders, under the leadership of Ardo Buba, the grandfather of Malam Danzabuwa. It has a landmass of 612 square Kilometres (336 square miles) with population of 277, 099 people (2006 Census). Bichi shares boundaries with Kunchi LG (North), Tsanyawa LG (East), Bagwai LG (South-East), Dawakin Tofa (South-West) and Dambatta LG (North-West). The geographical coordinates of Bichi Local Government, Kano are: 12.233914 (12º 14′ 02.1″N) and 8.279434 (8º 16′ 46.0″E). The significant percentage of population of people in Bichi are farmers, practicing farming on subsistent scale. Cereals (Guinnea-corn, maize rice and millet) are the major crops produced by farmers in this area of the state.

Temperature and humidity have very wide range in Bichi in particular and Kano in general, the mean daily maximum and minimum temperatures of the year is 43.00ºC and 15.85ºC respectively, the year is divided into wet and dry seasons, the dry season last from October to May during the months of December and January the harmattan is at its peak blowing dusts accumulated from the Sahara and at this time temperature can fall below 15ºC. From March to May, however, the dry cold air turns hot rising to about 32ºC (Ahmed, 2010). Rainfall is concentrated from June to September which is preceded by violent dust storms mainly during the month of May (Abdulazeez, 2015). The average annual rainfall is 870 mm about 58% of this fall in July and August; rainfall varies considerably from year to year ranging from 635 mm to 889 mm (Ahmed, 2010).

Collection and Preparation of Samples

Fifteen (15) farm (or agricultural) soil samples were collected from 15 farm sites in Bichi and other four (4) selected neighboring communities in Kano State. In each location or farm site, soil was collected from different spots and were thoroughly mixed together to form a good representative sample of the location. The sample were first dried in the Sun for 4 or 5 days before they were later dried in a temperature-controlled oven at 105°C for 24 hours for constant weight of the sample to be attained. Dried samples were then pulverized or crushed into powder form using Agate mortar and pestle. The crushed samples were then sieved with a 2 mm mesh sieve to obtain homogeneous sample (Hossain *et al*., 2012). About 200 g of each of the samples were weighed and transfer into a marked, thoroughly cleaned, and uncontaminated cylindrical plastic container of uniform size and sealed for 4 weeks to allow Radon and its short-lived progenies reach secular equilibrium at ambient temperature prior to gamma spectroscopy measurements (Ajayi, 2009; Issa, 2013).

Measurement of Radioactivity of Soil samples:

The activity concentrations of primordial radionuclides in the soil samples were measured using the gamma spectrometric method. NaI doped with Thallium detector (model: 802) of dimension 7.62 cm by 7.62 cm housed in a 6cm thick lead shield and lined with Cadmium (Cd) and Copper (Cu) sheets, in order to resist background radiation, was connected to a personal computer-based data acquisition system, which has Genie 2000 (VI.3) software from Canberra through 16,000 Multi-Channel-Analyzer (MAC). The detector was calibrated before using for the analysis. Energy and efficiency calibrations were performed. The energy calibration of the detector was done using different gamma sources of ^{60}Co (1173.2 and 1332.5 KeV), ^{137}Cs (661.9 KeV) and ^{22}Na (511 and 1274 KeV). The full width at half maximum (FWHM) corresponds to the resolution for the detector, and it has been shown that the resolution of a detector is directly proportional to the gamma ray energy (Hossain *et al*., 2012; Akkurt, 2014). The samples (15 agricultural/farm soil samples) were placed on the NaI(Tl) detector and each sample was set to counting time of 29,000s. This time is long enough for the detector to analyze the spectrum with the peaks of interest clearly shown and well distinguished. In NaI(Tl) analysis, the count rate of ^{238}U in the soil sample was estimated from the gamma-ray peak of ^{214}Bi (1.760 MeV), ^{232}Th from gamma-ray peak of ^{208}Tl (2.615 MeV), and ^{40}K from gamma-ray peak of ^{40}K (1.460 MeV) itself. The count rates under the photo peak of each of the primordial radionuclide for both detectors were converted to activity concentration, A using the Eqn. 1; (Akkurt, 2014; Isinkaye *et al*., 2015).

$$A = \frac{N \times 1000}{\epsilon_\gamma I_\gamma m t} (Bq/kg) \quad (1)$$

where A is the activity concentration of the radionuclide in the sample, N is the net counts or counting area under photo peak, ϵ_γ is the efficiency of the detector for a particular γ-ray energy, m is the mass of each sample, I_γ is the intensity of the emitted gamma-ray, and t is the counting time.

Estimation of Radiation Exposure Indicators:

Radium Equivalent Activity (Ra_{eq}):

Ra_{eq} is an index indicator that accounts for the contribution of each of the natural radioactivity to the total dose of the sample being investigated. It is the weighted sum of the activities of ^{40}K, ^{238}U and ^{232}Th in the sample being investigated with the assumption that 4810 $Bq.kg^{-1}$ of ^{40}K, 370 $Bq.kg^{-1}$ of ^{238}U, and 259 $Bq.kg^{-1}$ of ^{232}Th contribute the same gamma dose rate. Ra_{eq} was calculated using Eqn. 2, (Ajayi, 2009; Srilatha *et al*., 2015):

$$R_{a_{eq}}(Bq.Kg^{-1}) = A_U + 1.43A_{Th} + 0.077\,A_K \quad (2)$$

Where A_u, and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

Absorbed Dose Rate in Air (D):

The absorbed dose rate (outdoor), in $nGy.h^{-1}$, at a height of 1.0 m above the surface of the earth or ground in the study locations were estimated using Eqn. 3, (UNSCEAR, 2000):

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

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively measured in $Bq.kg^{-1}$.

Annual Effective Dose Rate (AEDE):

The outdoor annual effective dose equivalent due to activity concentrations of natural radioactivity obtained in the soil samples was calculated using Eqn. 4, (UNSCEAR, 2000; Olatunji *et al*., 2022):

$$\text{AEDE}\ (mSv.y^{-1}) = D \times T \times DCF \times OF \quad (4a)$$

where D is absorbed dose rate; DCF, the dose conversion factor is 0.7 $SvGy^{-1}$, OF, the outdoor occupancy factor is 0.2, and T, the annual exposure time is 8760 hyr^{-1} (IAEA, 1994). So, substituting these values in Eqn. 4a, we have:

$$\text{AEDE} = D(nGyh^{-1}) \times 8{,}760\text{hry}^{-1} \times 0.7 \times 0.2 \times (10^3\text{mSv}/10^9)\text{nGy} \quad (4b)$$

External Hazard Index (H_{ex}):

The external hazard index is a useful indicator for safety standard regulation and radiation protection from the emission of gamma radiation by various radioactive substances, and it was determined using Eqn. 5 as follows, (UNSCEAR, 2000; Raghu *et al*., 2016):

$$H_{ex} = \frac{A_K}{4810} + \frac{A_U}{370} + \frac{A_{Th}}{259} \quad (5)$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

Internal Hazard Index (H_{in}):

The internal exposure to radon and its daughter product is quantified by the internal hazard index which is given by Eqn. 6, (UNSCEAR, 2000; Raghu *et al*., 2016):

$$H_{in} = \frac{A_K}{4810} + \frac{A_U}{184} + \frac{A_{Th}}{259} \quad (6)$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

Gamma Index (I_γ):

Gamma index is the estimation of the level of gamma radioactivity associated with different concentrations of specific radionuclides (Ononugbo *et al*., 2016):

$$I_Y = \frac{A_K}{3000} + \frac{A_U}{300} + \frac{A_{Th}}{200} \quad (7)$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

Materials with $I_Y > 1$ should be avoided in building construction as such will deliver dose rate higher than 1 $mSvy^{-1}$ to the occupant of such buildings (WHO, 2008);

Annual Gonad Equivalent Dose (AGED):

Annual gonad equivalent dose is concern with the exposure received by body organs in the study areas due to specific activities of natural radioactivity in the soil. The gonads, the active bone marrows and the bone surface cells are considered as the organs of interest. AGED is determined using Eqn. 8, (Issa, 2013):

$$AGED\ (mSvy^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (8)$$

Where $A_{Ra} = A_U$, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively

Excess Lifetime Cancer Risk (ELCR):

Excess Lifetime Cancer Risk is the probability of developing cancer over a life time at a given level of exposure a higher value of ECLR implies higher probability induction of cancer of the individual that was exposed. It calculated using Eqn. 9, (Ononugbo et al., 2016):

$$ELCR = AEDE \times DL \times RF \times 10^{-3} \quad (9)$$

Where the average lifetime, DL = 45.5 years in Nigeria (WHO, 2008); and the Risk Factor, RF = 0.05.

Results and Discussion

Table 1: Activity Concentrations of Natural Radioactivity in Farm Soil in Bichi and Neighboring Communities (in $BqKg^{-1}$).

Community	Description	Location GPS	^{40}K ($BqKg^{-1}$)	^{238}U ($BqKg^{-1}$)	^{232}Th ($BqKg^{-1}$)
Bichi town	BCT/01	12.240149, 8.233505	649.87±32.43	13.03 ± 1.26	8.49± 0.48
	BCT/02	12.215570, 8.238405	501.66± 25.06	20.50± 2.23	11.91± 0.69
	BCT/03	12.221241, 8.212053	606.15± 30.31	15.69± 1.52	9.01± 0.53
	Range		476.60 – 682.30	11.77 – 22.73	8.41 – 12.69
	Mean + SD		**585.80 ±29.27**	**16.41± 1.67**	**9.80 ± 0.57**

Danzabua	DZB/01	12.350167, 8.176153	713.45± 36.01	22.84± 2.55	12.34± 0.79
	DZB/02	12.350135, 8.109997	578.33± 29.23	13.89± 1.61	6.89± 0.39
	DZB/03	12.400112, 8.045867	510.64± 25.88	17.32± 1.68	7.71± 0.43
	Range		484.76 – 749.46	12.28 – 25.39	6.50 – 13.13
	Mean + SD		**600.81 ± 30.37**	**18.02 ± 1.95**	**8.98 ± 0.54**
Chiromawa	CRW/01	12.289186, 8.179695	470.01± 23.55	28.61± 3.18	13.44± 0.75
	CRW/02	12.349931, 8.120318	661.74 ± 33.03	19.03± 2.11	9.89± 0.56
	CRW/03	12.310138, 8.168443	531.62 ± 26.56	12.84± 1.60	16.27± 0.92
	Range		446.46 – 694.77	11.24 -31.79	9.33 – 17.19
	Mean + SD		**554.46 ± 27.71**	**20.16 ± 2.30**	**13.20 ± 0.74**
Dan Gwarzo	DGZ/01	12.289299, 8.178598	454.66± 22.74	18.22± 1.77	10.41± 0.61
	DGZ/02	12.281329, 8.178202	472.14± 23.01	24.42± 2.67	9.43± 0.54
	DGZ/03	12.275722, 8.183745	560.26± 28.08	27.57± 2.74	14.11± 0.80
	Range		431.92 – 588.34	16.45 – 30.31	8.89 – 14.91
	Mean + SD		**495.69± 24.61**	**23.40 ± 2.39**	**11.32 ± 0.65**
Tabari	TBR/01	12.224008, 8.205804	691.50± 34.53	20.31± 2.25	10.10± 0.58
	TBR/02	12.224113, 8.205836	488.71± 24.44	11.87± 1.15	17.01± 0.99
	TBR/03	12.378455, 8.211331	434.04± 21.70	13.59± 1.61	11.31± 0.66
	Range		412.34 – 726.03	10.70 -22.56	9.52 – 18.00
	Mean + SD		**538.08± 26.89**	**15.26 ± 1.67**	**12.81 ± 0.74**

Table 1 displays the activity concentrations of natural radioactivity in farm soils in Bichi and neighboring communities. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Bichi and its neighboring communities ranged from: 476.60 – 682.30 (mean: 585.80 ± 29.27), 11.77 – 22.73 (mean: 16.41± 1.67) and 8.41 – 12.69 (mean: 9.80 ± 0.57) $BqKg^{-1}$ accordingly in Bichi town; 484.76 – 749.46 (mean: 600.81 ± 30.37), 12.28 – 25.39 (mean: 18.02 ± 1.95) and 6.50 – 13.13 (mean: 8.98 ± 0.54) $BqKg^{-1}$ respectively in Danzabua; 446.46 – 694.77 (554.45 ± 27.71), 11.24 – 31.79 (mean: 20.16 ± 2.30) and 9.33 – 17.19 (mean: 13.20 ± 0.74) $BqKg^{-1}$ correspondingly in Chiromawa; 431.92 – 588.34 (mean: 495.69 ± 24.61), 16.45 – 30.31 (mean: 23.40 ± 2.39), and 8.89 – 14.91 (mean: 11.32 ± 0.65) $BqKg^{-1}$ respectively in Dan Gwarzo; and, 412.34 – 726.03 (mean: 538.08 ± 26.89), 10.70 – 22.56 (mean: 15.26 ± 1.67), and 9.52 – 18.00 (mean: 12.81 ± 0.74) $BqKg^{-1}$ accordingly in Kabari (Tabari).

The activity concentrations of ^{40}K in all the farms in Bichi and other selected communities in its environs in Kano State were greater than the world average value of 400 $BqKg^{-1}$ (UNSCEAR, 2000; Olatunji et al., 2022). Similar results were obtained in other studies carried out by scholars all around the world. This is due to the fact that ^{40}K is a macronutrient and the most abundant radionuclide found in the soil and our environment. Also, the activity concentrations of ^{238}U and ^{232}Th recorded in this study in all the selected farms in Bichi and its neighboring communities were less than the world average values of 35 $BqKg^{-1}$ and 30$BqKg^{-1}$ respectively. The lower values of ^{238}U and ^{232}Th recorded in the farm soils were consequence of their abundance in the environment.

Table 2: **Radium Equivalent Activity ($Ra_{eq.}$), Hazard indices, Gamma (or Radioactivity Level) Index (Iγ), Absorbed Dose Rate (D), Annual Effective Dose Rate (AEDR), Annual Gonad Equivalent Dose (AGED) and Excess Lifetime Cancer Risk (ECLR) of Cultivated/Farm Soils in Bichi and Neighboring communities, Kano.**

Description	**Ra_{eq} ($BqKg^{-1}$)**	**Hazard Indices**		**Gamma Index (Iγ)**	**Adsorbed Dose Rate, D ($nGy.h^{-1}$)**	**AGED ($mSv.y^{-1}$).**	**AEDR ($mSv.y^{-1}$).**	**ELCR x 10^{-3}(**
		$H_{ex.}$	**$H_{in.}$**					
BCT/01	75.211	0.203	0.239	0.303	38.247	279.810	0.0469	0.1067
BCT/02	76.159	0.206	0.262	0.295	37.584	270.650	0.0461	0.1049
BCT/03	75.248	0.203	0.246	0.299	37.967	276.475	0.0466	0.1060
Mean	**75.539**	**0.204**	**0.249**	**0.299**	**37.933**	**275.645**	**0.0465**	**0.1059**
DZB/01	95.422	0.258	0.320	0.376	47.756	346.180	0.0586	0.1333
DZB/02	68.274	0.184	0.222	0.274	34.695	253.316	0.0425	0.0967
DZB/03	67.665	0.183	0.230	0.266	33.952	246.088	0.0416	0.0946
Mean	**77.120**	**0.208**	**0.257**	**0.305**	**38.801**	**281.861**	**0.0476**	**0.1082**
CRW/01	84.020	0.227	0.305	0.319	40.935	292.167	0.0502	0.1142
CRW/02	84.127	0.227	0.279	0.333	42.360	307.929	0.0520	0.1183
CRW/03	77.041	0.208	0.243	0.301	37.928	274.613	0.0465	0.1058
Mean	**81.729**	**0.221**	**0.276**	**0.318**	**40.408**	**291.570**	**0.0496**	**0.1128**
DGZ/01	68.115	0.184	0.234	0.264	33.665	242.577	0.0413	0.0940
DGZ/02	74.260	0.201	0.267	0.286	36.666	263.127	0.0450	0.1024
DGZ/03	90.887	0.245	0.320	0.349	44.623	320.093	0.0547	0.1244
Mean	**77.754**	**0.210**	**0.274**	**0.300**	**38.318**	**275.266**	**0.0470**	**0.1069**

TBR/01	87.999	0.238	0.293	0.349	44.319	322.107	0.0544	0.1238
TBR/02	73.825	0.199	0.232	0.288	36.137	261.235	0.0443	0.1008
TBR/03	63.184	0.171	0.208	0.247	31.209	225.557	0.0383	0.0871
Mean	**75.003**	**0.203**	**0.244**	**0.295**	**37.222**	**269.633**	**0.0457**	**0.1039**

Table 2 reveals the estimated values of Radium equivalent activity ($Ra_{eq.}$), External hazard index ($I_{ex.}$), Internal hazard Index ($I_{in.}$), Gamma Index (I_γ), Absorbed dose rate (D), Annual Gonad Equivalent Dose (AGED), Annual Effective Dose Rate (AEDR) and Excess Lifetime Cancer Risk (ELCR) of farm soils in Bichi and its neighboring communities. The $Ra_{eq.}$ of farm soils in Bichi and neighboring communities ranged from 63.184 – 95.422 $BqKg^{-1}$ with the mean value of 77.429 $BqKg^{-1}$. All of the recorded values of $Ra_{eq.}$ in the study areas are lower than the world permissible limit of 370 $BqKg^{-1}$(UNSCEAR, 2000; Srilatha *et al*., 2022). The external hazard index, I_{ex} of the farm soils ranged from0.171 - 0.258, and the estimated average of I_{ex} in all the farm soils was 0.209 while the Internal hazard index of the farm soils in Bichi and the neighboring communities ranged from 0.208 – 0.320 with the average value of 0.260. All the estimated and mean values of I_{ex} and I_{in} in the study areas were less than 1 (Unity) which is the maximum permissible limit for I_{ex} (UNSCEAR, 2000; Olatunji *et al*., 2022; Srilatha *et a*l., 2015).

The Gamma index, I_γ, of the farmland recorded in Bichi and its neighboring communities ranged from0.247 – 0.376 and the estimated mean of I_γ in all the study sites was 0.303. All the values obtained in the study for I_γ are less than the maximum permissible limit of Unity (UNSCEAR, 2000; Olatunji *et al*., 2022; Srilatha *et a*l., 2015) proposed for safety of farmers and people living in this communities. The Absorbed dose rate, D, of the farm soils in Bichi and its neighboring communities ranged from 31.209 – 47.756, and the estimated mean for absorbed dose rate, D, in all the selected farms was 38.536 $nGy.h^{-1}$. All these values (estimated and average) of absorbed dose rate, D, reported in this study are less than the world average value of 59.0 $nGy.h^{-1}$ (UNSCEAR, 2000; Srilatha *et al*., 2015).

The annual gonad equivalent dose (AGED), with has to do with exposure of reproductive organs to natural radioactivity, of the farm soils ranged from 225.557 – 346.180 $mSv.y^{-1}$. The mean value of AGED in the selected farms in the communities was 278.795 $mSv.y^{-1}$. A slightly higher values of AGED was recorded in four (4) out of the fifteen selected farms in the communities. These include: 346.180 $mSv.y^{-1}$ in (DZB/01), 307.929 $mSv.y^{-1}$ in (CRW/02), 320.093 $mSv.y^{-1}$in (DGZ/03) and 322.107 $mSv.y^{-1}$in (TRB/01). This is due to farming methods and usage of manure to boost the yield in the affected farms. However, the mean AGED value reported in all the farms in the study area were 278.795 $mSv.y^{-1}$which is lower than the world average value of 300.0 $mSv.y^{-1}$ and poise no immediate threat to people in these communities.

From Table 2, the annual effective dose rate, (AEDR), in the study areas ranged from 0.038 – 0.058 $mSv.y^{-1}$with the mean value of 0.047 $mSv.y^{-1}$. All the calculated values together with the mean in all the selected farm sites were less than the standard value of 0.070 $mSv.y^{-1}$which is the maximum permissible limit adopted for AEDR. The excess lifetime cancer risk (ELCR) of the farm soils in Bichi and its neighboring communities ranged from 0.087 x 10^{-3} – 0.133 x 10^{-3}, with the average value of 0.108 x 10^{-3}. All these recorded of values of ELCR are less than both the world average value of 1.45 x 10^{-3} and standard value of 0.29 x 10^{-3} (UNSCEAR, 2000; Olatunji *et al.*, 2022).

Table 3: Comparison of radiological hazard indices obtained in farm soils in Bichi and its neighbouring communities with similar studies

Location	H_{in}	H_{ex}	I_γ	Ra_{eq} ($BqKg^{-1}$)	D ($nGy.h^{-1}$)	AGED ($mSv.y^{-1}$).	AEDR(E) ($mSv.y^{-1}$).	Reference
Malaysia/Kedah	-	0.86	1.07	458.79	141.62	-	0.169	Alzuibaidi *et a*l., 2016.
Vietnam	-	0.43	-	-	71.72	-	0.540	Huy *et al.*, 2012.
India	-	-	-	-	97.47	-	0.120	Mehra & Singh, 2011.
Saudi Arabia	-	0.13	-	-	23.30	-	0.140	Alaamer, 2008.
Malaysia	-	1.19	-	-	202.04	-	0.230	Musa *et al.*, 2011.
Jordan	-	0.28	-	-	51.50	-	0.060	Al-Hamarneh & Awadallah. 2009.
Pakistan	-	0.39	0.14	-	68.83	-	0.340	Rafique *et al.*, 2011.
India	-	0.53	0.71	-	90.10	-	0.110	Zubair *et al.*, 2013.
Saudi Arabia	0.49	0.44	-	149.51	84.98	-	0.520	Badghish & Hamidalddin, 2022.
Egypt/Rashi	-	0.40	0.52	-	118.36	-	145.160	El-Kameesy et al., 2016.
Turkey/Rize	-	0.34	-	125.00	56.90	-	0.070	Durusoy & Yildirim, 2017.
India/Karnataka	-	0.19	0.29	-	33.23	-	4.070	Chandrashekara *et al.*, 2014.
Nigeria/Ondo	0.047	0.03	-	12.44	5.83	40.39	0.007	Ononugbo *et al.*, 2023.
Nigeria/Kano	0.260	0.21	0.30	77.43	38.56	278.80	0.047	Present Study.
World Average	**1.000**	**1.00**		**370.00**	**59.00**	**300.00**	**0.070**	**UNSCEAR, 2000**

Table 3 reveals the values of radiological hazard indices/parameters reported by other scholars in similar studies carried out in different locations around the world and was compared with values reported in this study. The internal hazard index in this study (0.26) was greater than the value reported by Ononugbu *et al.*, 2023; but less than the value recorded by Badghish & Hamidalddin, 2022 and the maximum permissible limit (Unity). The external hazard index (0.21) was also higher than the values reported by Alaamer, 2008; Chandrashekara *et al.*, 2014; and Ononugbu *et al.*, 2023; but lower than the maximum permissible limit (Unity) and values recorded by the other scholars like: Huy *et al.*, 2012; Musa *et al.*, 2011; Rafique *et al.*, 2011; Zubair *et al.*, 2013; Badghish & Hamidalddin, 2022; and host of others. The Radium equivalent activity, Ra_{eq}, (77.43 $BqKg^{-1}$) was greater than value recorded by Ononugbu *et al*., 2023; but lower than the world average value (370.00 $BqKg^{-1}$) and other values reported by scholars in different locations.

The absorbed dose rate, D, of farm soils in Bichi and its neighbouring communities reported in the study (38.56 $nGyh^{-1}$) was higher than values reported by Ononugbu *et al*., 2023; Chandrashekara *et al*., 2014; and Alaamer, 2008; but lower than the world average value of 59.00$nGyh^{-1}$and values reported by: Alzuibaidi *et al*., 2016; Huy *et al*., 2012; Mehra & Singh, 2011; Musa *et al*., 2011; Rafique *et al*., 2011; Zubair *et al*., 2013; Badghish & Hamidalddin, 2022; Durusoy & Yildirim, 2017; and other scholars captured in Table 3. The value of AGED obtained in this study was also greater than the value reported by Ononugbu *et al*., 2023; but lower than the world average value. The value of AEDR reported in this study was lower than all other values reported by other scholars with the exception of value obtained by Ononugbu *et al*., 2023.

Conclusion

In all the farm soils in Bichi and its neighbouring communities, the activity concentrations of ^{40}K, and its mean values in each of the selected communities, were greater than the world average value of 400 $BqKg^{-1}$, the higher values of ^{40}K obtained in the study was due to the fact that ^{40}K, apart from being a macronutrient in the soil, is the most abundant natural radionuclide in the soil. However, the activity concentrations of ^{238}U and ^{232}Th reported in farm soils in the study area were all lower than their corresponding world average values of 35 $BqKg^{-1}$ and 30$BqKg^{-1}$ respectively. The values of radiological hazard parameters: External and Internal hazards indices; gamma index; Radium equivalent activity; Absorbed dose rate; Annual gonad equivalent dose and Annual effective dose rate, were all estimated and were found to be lower than their respective maximum permissible limit. This however, implies that there is no threat to lives of farmers working on these farms and the population living in the study area. A comparison of all these values with the ones obtained and reported in other similar studies, shows that the results obtained in this study are within the range of results obtained in different locations where similar study has been carried out.

Conflict of Interest

The authors solemnly declared no conflict of interest.

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