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Natural Radionuclides in Rice Samples Cultivated in Selected Farmlands of Birnin Kebbi, Kebbi State, Nigeria: An Evaluation of Bioaccumulation.

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ABSTRACT
This study assessed the radiological safety of rice cultivated in Birnin Kebbi, Kebbi State, Nigeria, by measuring the concentrations of natural radionuclides in farmland soils and the corresponding rice grains. Gamma spectrometry analysis revealed activity concentrations in soil averaging 14.60, 21.47, and 328.60 $Bqkg^{-1}$ for ^{238}U, ^{232}Th, and ^{40}K, respectively. Concentrations in rice grains were significantly lower, averaging 3.79, 1.75, and 97.86 $Bqkg^{-1}$ for the same radionuclides. All consequent radiological indices including radium equivalent activity, absorbed gamma dose rate, and annual effective dose were all found to be well within internationally accepted safety limits. Soil to rice transfer of natural radionuclides was computed. The mean soil-to-rice transfer factors were 0.22, 0.08, and 0.32 for ^{238}U, ^{232}Th, and ^{40}K, respectively, showing low bioaccumulation factors. The findings indicate that rice consumption from the studied area does not pose a significant radiological health risk to the population. This work establishes crucial baseline data for environmental monitoring and contributes to the ongoing assessment of food safety in a vital Nigerian agricultural area.
Keywords: Natural radionuclides; Rice; Soil; NaI(Tl) detector; Radiological hazard; Dose assessment Kebbi State, Nigeria

1.0 INTRODUCTION

Natural radionuclides present in the environment are transferred to the plants mainly through uptake from soil through roots and direct absorption through aerial parts of the plants (Linsalata, 1994). The former depends on the radionuclide activity concentrations in the soil, and the latter on the rate of radionuclide deposition from the atmosphere. While some radionuclides are taken up as homologues of essential elements, other radionuclides are taken up irrespective of their biological necessity. Besides the well-known 16 essential elements for the growth and reproduction of vegetation (Linsalata, 1994). Examining the transfer of natural radionuclides such as ^{238}U, ^{232}Th and their progeny are significant due to being present everywhere in the environment (Hasan., et al. 2010; Pulhani., et al, 2005*)*. The transfer of natural radionuclides from soil to food crops is perceived as one of the significant pathways to people (IAEA, 1982). The translocation of radionuclides alongside nutrients through the assimilation of minerals, and gather in different parts or even up to the eatable parts would bring about the relating increment of the radiation portion and causes health risks in the humans.

Soil-to-plant and plant-to-human body is one of the foremost corridors for transmission of radionuclides to human organism (IAEA, 1982). After uptake by root, radionuclides are transferred to plant along with other nutrients or mineral necessary for their growth and reproduction of the plant (Joshy et al., 2011). These radionuclides translocate toward different parts of plant through the vascular system comprising the xylem and phloem; accumulate in several parts including the edible portions and would lead to endless

radiation dose to man once consumed (Pulhani et al., 2005; Carini, 2001). Therefore, it is an important study to the spatial erraticism of natural radioactivity in soil and related radiation exposures through specific land produced food-stuffs.

According to the Food and Agriculture Organization (FAO, 2020), Nigeria is the largest consumer of rice in Africa, accounting for about 30% of the continent's total rice consumption. The country's rice consumption has increased from 4.6 million metric tons in 2010 to 6.3 million metric tons in 2020 (USDA, 2020).

Among the various kinds of food, rice is regularly consumed worldwide as well as countrywide like Nigeria. Consequently, human radiation exposure owing to the ingestion of radionuclide via rice consumption is a global concern (Alrefae and Nageswaran, 2013; Alrefae, 2012; IAEA, 1989; Yu and Mao, 1999).

Despite Kebbi State's strategic role in national food security, there is a paucity of data on the baseline levels of natural radioactivity in its farmlands and the subsequent bioaccumulation in its rice produce. The soil-to-plant transfer factor is one of the key parameters extensively used for the estimation of internal radiation dose from radionuclides through food consumption (Tsukada et al., 2002).

Nevertheless, an overall review of literature reveals that (Mgbeokwere et al.,2023; Ugbede et al..2021; Ilemona et al.,2016) from Nigeria conducted similar studies to obtain a radiological mapping on rice grown in southern and eastern region. Since studies on the uptake of radionuclides via intake of it are still limited in the area under investigation, the present study would therefore make a valuable contribution to the establishment of a standard database of the natural radioactivity of soil and rice in Kebbi state. It can also serve as a reference for an assessment of radiological impact via rice consumption by the inhabitants of Kebbi state and bordering states.

2 MATERIALS AND METHODS

2.1 Sample Collection and Preparation

A total of thirty paired samples of rice and its corresponding soil were collected from six distinct farmlands in Birnin Kebbi. At each sampling point, soil samples were taken from the plough layer 0–20cm depth using a stainless-steel auger, as radionuclides are taken up by crops primarily through root absorption (Mgbeokwere et al,. 2021). Five sub-samples were collected within a 2m radius around the rice harvesting spot and thoroughly mixed to form a composite sample. Simultaneously, mature rice grains samples were hand-harvested from the same area. All samples were placed in labeled, airtight polyethylene bags, stored in cool boxes, and transported to the laboratory within 6 hours to prevent biochemical changes and moisture loss (Perez et al.,2001). Rice grains were manually dehulled using mortar and pestle to obtain brown rice, then rinsed three times with water to remove surface dust and any unwanted residues. Washed grains were spread on a tray and dried at 70°C for 48hrs in a forced-air oven until constant weight was achieved.

Similarly, thirty corresponding soil samples were collected in accordance to rice sampling collection point presented in Table 1 and Table 2, the soil samples were air-dried in a dust-free environment at room temperature 25°C for 72 hours, then oven-dried at 105 °C for 24 hours to constant weight. The pulverized samples were sieved through 40- and 50-mesh screens (IAEA, 2003).

Gamma rays were detected after at least 60 days for the preparation of the sealed samples, since time interval is necessary to achieve secular equilibrium in the ^{238}U and ^{232}Th decay chains (IAEA, 2003). In this investigation, 260g of soil and rice samples were packed in a 600cm^3 Marinelli beaker. The gathered samples need careful handling because radon has a short half-life. For gamma-ray spectrometry, all samples were prepared in Marinelli beaker containers.

Table 1. Rice sample codes and the sampling site

Sample site	Sample Code	Number of Samples
DUKKU11	DR11	5
DUKKU21	DR 21	5
DUKKU31	DR 31	5
MAURIDA11	MR11	5
MAURIDA21	MR21	5
MAURIDA31	MR31	5

Table 2. Soil sample codes and the sampling site

Sample site	Sample Code	Number of Samples
DUKKU11	DS11	5
DUKKU21	DS21	5
DUKKU31	DS31	5
MAURIDA11	MS11	5
MAURIDA21	MS21	5
MAURIDA31	MS31	5

2.2 Gamma-ray Spectrometry

In this study, the activity concentrations of natural radionuclides in rice and corresponding soil samples were measured with a NaI(Tl) scintillation detector. This detector was connected via an amplifier base to a GS-2000-Pro plus multichannel analyzer for sample analysis. It was housed in a 10cm thick cylindrical lead shield to minimize background radiation from natural sources and shield it from nearby radiation influences.Samples were placed directly on the detector surface and counted for 36,000 seconds each, with consistent configuration and geometry throughout. A computer-based multichannel analyzer (MCA GS-2000-Pro) handled gamma spectra acquisition and analysis via the comparative method. Activity concentrations were reported in Bqkg^{-1} on a dry weight basis. The ^{232}Th activity was determined via 2614.5keV gamma line from ^{208}Tl, while ^{238}U was assessed via the 1764.5keV line of ^{214}Bi. The ^{40}K activity concentration relied on its 1460.0keV gamma line. Each radionuclide's activity concentration A (Bqkg^{-1}) was computed using Equation 1. (Akkurt *et al*., 2014; Isinkaye and Emelue, 2015):

$$A = \frac{C_{net}}{P_\gamma I\gamma m t} \quad (1)$$

Where A is the activity concentration (Bq kg^{-1}), C_{net} is the net count rate under the photopeak, ϵ_γ is the detector efficiency at the specific gamma-ray energy, I_γ is the absolute emission probability of the gamma ray, m is the sample mass (kg), and t is the counting time (s).

2.3 Evaluation of Radiological dose and risk Parameters

2.3.1 Radium equivalent activity (Ra_{eq})

The Radium Equivalent Activity (Ra_{eq}) serves as a composite index, representing the weighted sum of activity concentrations for ^{238}U, ^{232}Th and ^{40}K based on their respective gamma dose contributions. It is

computed using the standard conversion factors of 4810, 370, and 259Bqkg^{-1} for these radionuclides, respectively, as expressed in Equation 2. (Ajayi, 2009; Srilatha et al., 2015).

$$Ra_{eq}\,(\mathrm{Bqkg^{-1}}) = A_U + 1.43\mathrm{A_{Th}} + 0.077\mathrm{A_k} \quad (2)$$

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

2.3.2 Absorbed Dose Rate (D)

The absorbed dose (D) quantifies the energy deposited by radiation per unit mass of a medium. This refers specifically to the dose from gamma radiation measured in air one meter above ground, assuming a uniform distribution of radionuclides (Ocheje, 2020). The contributions from naturally occurring radionuclides are determined using the following expression (Avwiri et al., 2012)

$$\mathrm{D(nGyh^{-1})} = 0.427C_U + 0.662\mathrm{C_{Th}} + 0.0432\mathrm{C_k} \quad (3)$$

2.3.3 Annual Effective Dose Equivalent (AEDE)

The computed absorbed dose rates were used to calculate the Annual Effective Dose Equivalent (AEDE) received by the farmers. In calculating AEDE, dose conversion factor of 0.7SvGy^{-1} and the occupancy factor for outdoor of 0.25 (6h out of 24h) was used. The Annual Effective Dose was estimated using the following relation (Ononugbo et al., 2012):

$$\mathrm{AEDE(Outdoor)(mSvy^{-1})} = \mathrm{DR(nGyh^{-1})} \times 8760h \times 0.7SvGy^{-1} \times 0.2 \times 10^{-3}$$

(4)

2.3.4 **Excess Life Cancer Risk (ELCR)**

The annual effective dose serves as the basis for estimating the Excess Lifetime Cancer Risk (ELCR), as defined in Equation 5

$$ELCR = AEDE \times DL \times RF \quad (5)$$

Where *AEDE* is the Annual Effective Dose Equivalent (mSv y^{-1}), DL is average duration of life (70years), and RF is the Risk Factor i.e. fatal cancer risk per sievert. For stochastic effects, ICRP uses RF as 0.05Sv^{-1} for the public (Taskin.et al.,2009)

2.3.5 **Annual Gonadal Equivalent Dose (AGED)**

Safeguarding critical tissues such as the gonads, bone marrow, and bone surface cells is a fundamental objective within the radiation protection community (Ugbede *et al.*, 2021). The AGED is given as;

$$AGED\,(svy^{-1}) = 3.09C_U + 4.18C_{Th} + 0.314C_k \quad (6)$$

Where C_u, C_{Th}, and C_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K respectively

2.3.6 Representative Gamma Index (I_γ)

This model estimates the gamma (γ) radiation hazard posed by the natural radionuclides in the studied samples. The gamma activity index is defined by the following expression:

$$I\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{150} \quad (7)$$

The gamma activity index serves to estimate the annual effective dose attributable to external gamma radiation from surface materials (Avwiri et al., 2019). It also functions as a screening tool for identifying construction materials that may present a radiological health concern.

Values of $I\gamma \leq 1$ corresponds to an annual effective dose of less than or equal to $1mSvy^{-1}$, while $I\gamma \leq 0.5$ is equivalent to annual effective dose less or equal to $0.3mSv\ y^{-1}$.

2.3.7 Activity Utilization Index

The parametric model employed to calculate the in-air dose rates from the radionuclides (^{238}U, ^{232}TH, ^{40}K) in the soil samples is expressed by the following equation (Ugbede et al., 2021);

$$AUI = \frac{A_u}{50}XF_U + \frac{A_{Th}}{20}XF_{Th} + \frac{A_k}{500}XF_k \quad (8)$$

Where, A_u, A_{Th} and A_k are activity concentration in $Bqkg^{-1}$ for ^{238}U, ^{232}Th and ^{40}K.

F_u, F_{Th}, and Fk represent the fractional contributions of gamma radiation from the measured radionuclide concentrations to the total air dose rate (Sivakumar *et al., 2014)*. The values of F_u, F_{Th}, and Fk are given as 0.462, 0.604 and 0.041 for uranium, thorium and potassium respectively. Substituting the fractional contributions values, the equation becomes;

$$AUI = \frac{A_u}{50}X\ 0.462 + \frac{A_{Th}}{20}X\ 0.604 + \frac{A_k}{500}X\ 0.041 \quad (9)$$

AUI less than 2 corresponds to an annual effective dose of < 0.3 $mSvy^{-1}$ which is safe for the environment (Ugbede *et al.,* 2021).

2.3.8 Annual Committed Effective Dose (ACED)

Committed effective dose quantifies the total effective dose accumulated over a 70-year lifetime after radionuclide intake (internal exposure) (WHO, 2007). In this study, the committed effective dose for one year in rice grain samples was calculated across various age groups using the relation below (Darwish *et al.*,2015).

$$E = IxA\ x\ C\ \times\ 365 \quad (10)$$

Where I is the daily crop (rice) consumption ($24.8gd^{-1}$), A is the activity concentration in becquerel per kg ($Bqkg^{-1}$) and C is the age and radionuclide specific ingestion dose coefficient ($SvBq^{-1}$) as provided by ICRP (2007).

2.3.9 Bioaccumulation Factor (BAF)

Bioaccumulation factors are widely employed to quantify the transfer of natural radionuclides through the food chain, acting as a key measure in radiological evaluations. The bioaccumulation factor (BAF) measures the uptake of these radionuclides from soil into different plant parts via root absorption. This factor for natural radioactivity in the samples is determined using equation 11 (Ehlken and Kirchner, 2002; Chibowski and Gladysz, 1999; UNSCEAR, 2000).

$$BAF = \frac{Activity\ of\ natural\ radionuclide\ in\ plant\ (Bq.kg^{-1}dry\ weight)}{Activity\ of\ natural\ radionuclide\ in\ soil\ (Bq.kg^{-1}dry\ weight)} \quad (11)$$

3.0 RESULTS AND DISCUSSION

3.1 Activity Concentrations

Table 3. Activity concentrations of natural radionuclides ^{238}U, ^{232}Th, and ^{40}K (Bq kg^{-1}) and radium equivalent activity (Ra_eq, Bq kg^{-1}) in soil samples from Dukku and Maurida farmlands, Birnin Kebbi.

Sample ID	Location	^{238}U	^{232}Th	^{40}K	Ra_{eq}
DS11	DUKKU1	24.50±2.50	26.00±2.00	259.12±10.36	81.63
DS12		18.00±1.50	19.60±1.40	402.87±16.12	77.05
DS13		12.45±1.02	18.20±1.31	318.7±12.75	68.10
DS14		26.00±2.00	34.00±.2.50	480.60±18.98	111.63
DS15		13.50±1.10	17.84±1.30	373.82±15.01	73.40
DS21	DUKKU2	13.93±0.91	22.46±1.61	263.44±10.53	76.10
DS22		14.07±1.05	26.32±1.90	244.07±10.02	80.20
DS23		22.10±1.85	24.00±2.00	510.21±20.41	95.71
DS24		11.04±0.61	17.80±1.03	207.11±8.30	53.70
DS25		13.14±1.51	15.78±1.14	306.66±12.27	63.40
DS31	DUKKU3	24.00±2.00	27.00±2.00	440.05±17.60	96.49
DS32		12.99±0.80	27.00±2.00	235.39±9.42	77.70
DS33		15.11±0.98	20.12±2.24	327.11±9.41	73.80
DS34		25.00±2.00	28.00±2.00	489.07±19.57	102.70
DS35		17.77±1.57	22.50±1.41	382.21±15.30	79.38
MS11	MAURIDA1	11.11±0.76	18.40±1.01	418.08±16.72	69.61
MS12		12.22±1.55	20.93±1.50	245.40±9.82	69.70
MS13		13.76±1.61	20.80±1.30	214.33±8.57	60.01
MS14		15.36±1.01	23.66±1.92	344.83±12.64	80.81
MS15		10.97±0.68	16.63±1.20	299.12±11.96	63.20
MS21	MAURIDA2	13.68±0.88	19.02±1.37	252.99±10.12	68.10
MS22		13.14±0.82	21.15±1.53	294.96±11.80	73.10
MS23		10.15±0.58	22.86±1.66	242.18±9.61	67.90
MS24		14.54±1.07	24.33±1.75	349.77±14.03	83.70
MS25		12.11±0.78	20.60±1.26	378.90±15.15	70.74
MS31	MAURIDA3	15.55±0.88	19.30±1.15	277.45±12.01	64.51
MS32		13.64±0.89	21.36±1.53	216.10±8.64	68.20
MS33		16.74±1.09	22.86±1.64	176.60±7.06	69.30
MS34		18.30±1.19	31.11±2.23	458.96±18.36	106.70
MS35		19.21±1.71	15.80±1.15	447.97±17.92	86.80
Range		**10.15±0.58–26.00±2.00**	**13.86±1.01–34.00±2.23**	**176.60±7.06–510.21±20.41**	**52.44–111.63**
Mean		**14.60±1.11**	**21.47±1.55**	**328.60±12.92**	**77.07**

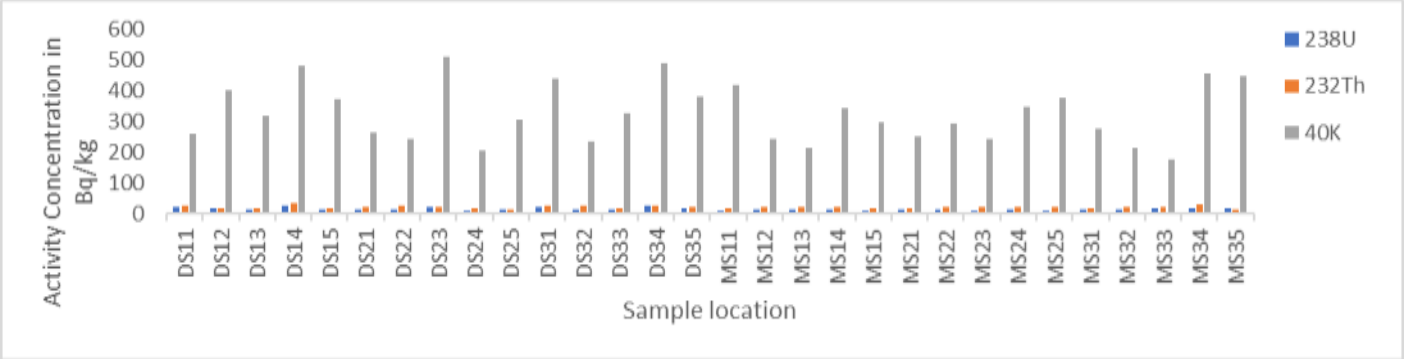

Figure 1: Activity Concentration of Natural radionuclides in soil

Table 4: Measured activity concentrations of ^{238}U, ^{232}Th, and ^{40}K (Bq kg^{-1}) in rice grains cultivated in Dukku and Maurida farmlands, Birnin Kebbi

Sample ID	Location	^{238}U	^{232}Th	^{40}K
DR11	DUKKU1	4.02±0.70	1.38±0.23	112.27±2.44
DR12		3.22±0.67	1.47±0.15	112.19±2.27
DR13		2.69±0.16	1.72±0.12	98.79±0.13
DR14		3.63±0.09	2.00±0.16	120.97±2.38
DR15		4.01±0.21	1.82±0.77	100.24±2.66
DR21	DUKKU2	3.44±0.61	2.03±0.13	92.87±1.85
DR22		3.81±0.03	2.09±0.40	90.79±1.40
DR23		4.94±0.26	1.60±0.17	124.99±2.45
DR24		2.76±0.04	1.34±1.11	85.01±1.13
DR25		4.19±0.15	1.31±0.17	100.07±0.13
DR31	DUKKU3	4.12±0.16	1.70±0.18	104.14±0.15
DR32		4.68±0.14	2.70±0.13	101.44±2.38
DR33		3.49±0.07	1.65±0.15	96.75±1.45
DR34		4.45±0.07	2.43±0.17	113.31±1.14
DR35		4.78±0.06	1.69±0.21	105.95±1.49
MR11	MAURIDA1	4.22±0.24	2.98±0.23	112.27±2.44
MR12		3.09±0.11	1.57±0.14	95.03±0.95
MR13		4.32±0.46	2.45±0.19	88.12±0.92
MR14		3.01±0.74	2.04±0.24	100.05±1.01
MR15		3.52±0.45	1.55±0.25	106.12±2.26
MR21	MAURIDA2	2.79±0.15	1.75±0.12	90.58±1.90
MR22		4.19±0.58	2.03±0.20	96.58±1.95
MR23		4.05±0.66	1.44±0.15	83.75±1.83
MR24		4.38±0.12	2.36±0.22	100.75±2.01
MR25		2.75±0.15	1.55±0.25	106.12±2.26
MR31	MAURIDA3	4.96±0.74	1.45±0.21	92.11±1.34
MR32		3.00±0.46	1.88±0.16	82.04±1.92
MR33		3.33±0.49	1.60±0.15	70.67±1.17

MR34	4.30±1.15	1.90±0.17	115.02±2.76
MR35	4.40±0.94	1.09±0.17	105.57±2.55
Range	**2.69±0.16-4.96±0.74**	**1.09±0.17-2.98±0.23**	**70.67±1.17-124.99±2.45**
Mean	**3.79±0.38**	**1.75±0.24**	**97.86±1.61**

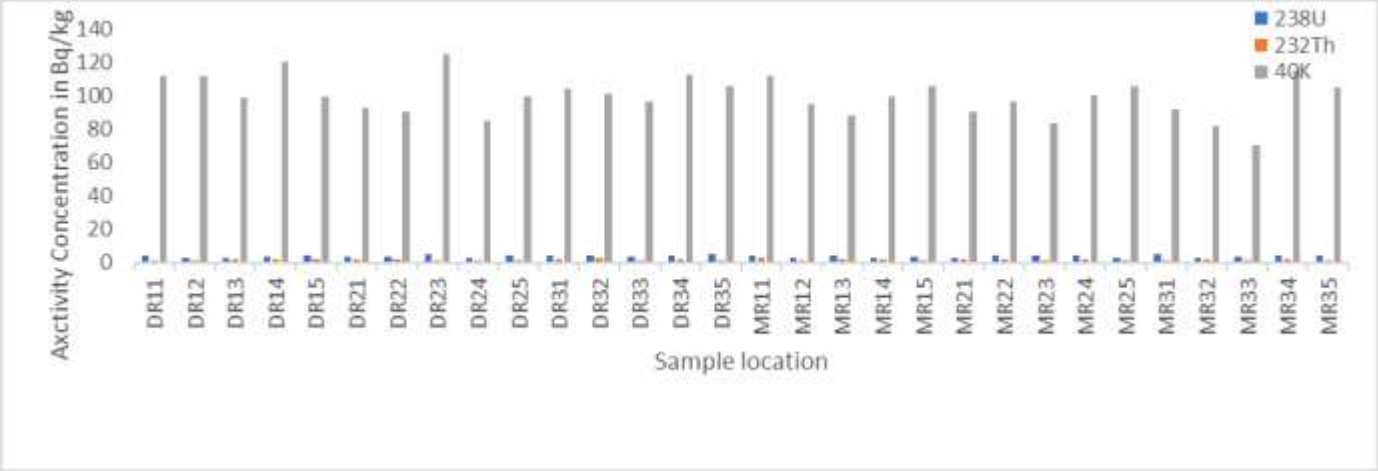

Figure 2: Activity concentration of natural radionuclides in rice

3.2 Radiation Hazard Parameters

Various radiation hazard parameters were computed from the activity concentrations of ^{238}U, ^{232}Th and ^{40}K using appropriate mathematical expressions. Results of the computations are presented in table 5.

Table 5. Derived external radiation dose rates and hazard indices for soil samples from Dukku and Maurida farmlands

Sample ID	D (nGy h^{-1})	AEDE (mSv y^{-1})	ELCR ($x10^{-3}$)	AUI	AGED (µSv y^{-1})	$I\gamma \leq 1$
DS11	37.83	0.05	0.19	0.50	274.89	0.60
DS12	36.95	0.05	0.18	0.66	268.52	0.60
DS13	32.49	0.04	0.14	0.49	218.25	0.51
DS14	52.59	0.06	0.26	0.80	382.14	0.83
DS15	35.99	0.04	0.15	0.56	236.91	0.60
DS21	31.04	0.04	0.13	0.48	225.19	0.50
DS22	30.35	0.04	0.13	0.46	236.72	0.49
DS23	45.98	0.06	0.19	0.76	334.15	0.39
DS24	24.49	0.03	0.10	0.31	177.95	0.39
DS25	30.05	0.04	0.13	0.46	206.31	0.48
DS31	45.75	0.06	0.22	0.71	332.44	0.72
DS32	30.54	0.04	0.13	0.47	233.46	0.48
DS33	33.02	0.04	0.14	0.51	238.16	0.52
DS34	48.86	0.06	0.24	0.77	355.02	0.76
DS35	37.74	0.05	0.19	0.59	274.24	0.60
MS11	33.68	0.04	0.17	0.58	244.74	0.54
MS12	28.86	0.04	0.12	0.44	207.26	0.45

MS13	27.86	0.03	0.14	0.35	202.44	0.44
MS14	37.90	0.05	0.19	0.57	275.45	0.60
MS15	29.86	0.04	0.13	0.46	200.44	0.47
MS21	29.53	0.04	0.13	0.45	206.08	0.47
MS22	31.77	0.04	0.14	0.48	226.36	0.50
MS23	29.52	0.04	0.13	0.45	207.8	0.47
MS24	37.26	0.05	0.12	0.58	261.61	0.58
MS25	33.84	0.04	0.17	0.55	245.89	0.54
MS31	30.41	0.04	0.15	0.42	221.00	0.48
MS32	27.66	0.03	0.12	0.42	205.03	0.43
MS33	27.77	0.03	0.12	0.42	210.06	0.42
MS34	53.52	0.07	0.23	0.84	337.07	0.84
MS35	42.26	0.05	0.18	0.65	269.53	0.67
Range	**24.49-53.52**	**0.03-0.07**	**0.12-0.26**	**0.31-0.84**	**177.95-382.14**	**0.39-0.83**
Mean	**35.18**	**0.05**	**0.16**	**0.54**	**250.50**	**0.56**

Table 6: Radiological dose parameters estimated for rice samples from Dukku and Maurida farmlands

Sample ID	D (nGy h^{-1})	AEDE (mSv y^{-1})	ELCR ($x10^{-3}$)	AGED (µSvy^{-1})
DR11	10.18	0.01	0.04	49.37
DR12	7.05	0.01	0.04	48.67
DR13	8.54	0.01	0.04	44.17
DR14	10.93	0.01	0.05	54.71
DR15	10.03	0.01	0.04	49.21
DR21	8.89	0.01	0.04	46.14
DR22	9.18	0.01	0.04	46.98
DR23	11.85	0.01	0.05	58.38
DR24	8.22	0.01	0.04	38.84
DR25	9.69	0.01	0.04	47.61
DR31	10.59	0.01	0.05	50.19
DR32	10.96	0.01	0.05	55.36
DR33	9.04	0.01	0.04	52.74
DR34	11.45	0.01	0.05	56.92
DR35	11.85	0.01	0.05	52.77
MR11	11.87	0.01	0.05	51.49
MR12	9.01	0.01	0.04	43.74
MR13	10.54	0.01	0.05	45.63
MR14	9.75	0.01	0.04	46.88
MR15	9.70	0.01	0.04	45.59
MR21	8.76	0.01	0.04	42.25
MR22	10.35	0.01	0.04	49.60
MR23	9.68	0.01	0.04	43.01
MR24	11.00	0.01	0.05	52.79

MR25	10.96	0.01	0.05	45.76
MR31	10.08	0.01	0.04	48.36
MR32	8.67	0.01	0.04	41.00
MR33	7.59	0.01	0.03	37.62
MR34	11.89	0.01	0.05	54.72
MR35	11.88	0.01	0.05	48.94
Range	**7.05-11.89**	**0.01-0.01**	**0.03-0.05**	**37.62-58.38**
Mean	**9.98**	**0.01**	**0.04**	**48.31**

Table 7. Total annual committed effective dose (ACED) for different age groups due to rice consumption

Sample ID	<1yr (mSvy^{-1})	1-7yrs (mSv y^{-1})	7-12yrs (mSv y^{-1})	12-17yrs (mSv y^{-1})	>17yrs (mSv y^{-1})
DR11	0.01	0.01	0.01	0.01	0.01
DR12	0.01	0.01	0.01	0.01	0.01
DR13	0.01	0.02	0.03	0.03	0.03
DR14	0.01	0.02	0.03	0.03	0.03
DR15	0.01	0.02	0.03	0.03	0.03
DR21	0.01	0.02	0.03	0.03	0.03
DR22	0.01	0.02	0.03	0.03	0.03
DR23	0.01	0.02	0.03	0.04	0.04
DR24	0.01	0.01	0.01	0.01	0.01
DR25	0.01	0.02	0.03	0.03	0.03
DR31	0.01	0.02	0.03	0.03	0.03
DR32	0.01	0.02	0.03	0.04	0.04
DR33	0.01	0.02	0.03	0.03	0.03
DR34	0.01	0.02	0.03	0.02	0.04
DR35	0.01	0.02	0.02	0.02	0.02
MR11	0.01	0.02	0.03	0.04	0.04
MR12	0.01	0.02	0.02	0.03	0.03
MR13	0.01	0.01	0.03	0.01	0.01
MR14	0.01	0.02	0.03	0.01	0.01
MR15	0.01	0.02	0.03	0.03	0.03
MR21	0.01	0.02	0.02	0.03	0.03
MR22	0.01	0.02	0.03	0.03	0.03
MR23	0.01	0.02	0.03	0.03	0.03
MR24	0.01	0.02	0.03	0.03	0.03
MR25	0.01	0.02	0.01	0.01	0.01
MR31	0.01	0.02	0.01	0.01	0.01
MR32	0.01	0.02	0.02	0.03	0.03
MR33	0.01	0.01	0.02	0.03	0.03
MR34	0.01	0.02	0.03	0.04	0.03
MR35	0.01	0.02	0.03	0.04	0.03
Range	**0.01-0.01**	**0.01-0.02**	**0.02-0.03**	**0.01-0.04**	**0.01-0.04**
Mean	**0.01**	**0.01**	**0.02**	**0.03**	**0.02**

Table 8: Soil-to-rice bioaccumulation factors of natural radionuclides (^{238}U, ^{232}Th, and ^{40}K) in Dukku and Maurida farmlands

Sample ID	Location	^{238}U	^{232}Th	^{40}K
DR11	DUKKU1	0.16	0.09	0.37
DR12		0.18	0.08	0.28
DR13		0.22	0.06	0.31
DR14		0.14	0.06	0.25
DR15		0.30	0.06	0.27
DR21	DUKUU2	0.25	0.05	0.35
DR22		0.27	0.08	0.37
DR23		0.22	0.07	0.25
DR24		0.25	0.08	0.41
DR25		0.32	0.08	0.33
DR31	DUKKU3	0.17	0.06	0.24
DR32		0.36	0.10	0.43
DR33		0.23	0.08	0.30
DR34		0.18	0.09	0.23
DR35		0.27	0.06	0.28
MR11	MAURIDA1	0.38	0.08	0.27
MR12		0.25	0.08	0.39
MR13		0.31	0.08	0.41
MR14		0.20	0.08	0.29
MR15		0.32	0.09	0.33
MR21	MAURIDA2	0.20	0.09	0.36
MR22		0.32	0.10	0.33
MR23		0.40	0.06	0.35
MR24		0.30	0.10	0.29
MR25		0.23	0.08	0.28
MR31	MAURIDA3	0.32	0.08	0.33
MR32		0.22	0.09	0.38
MR33		0.20	0.07	0.40
MR34		0.24	0.05	0.25
MR35		0.23	0.07	0.24
Range		**0.14-0.40**	**0.05-0.08**	**0.23-0.43**
Mean		**0.22**	**0.08**	**0.32**

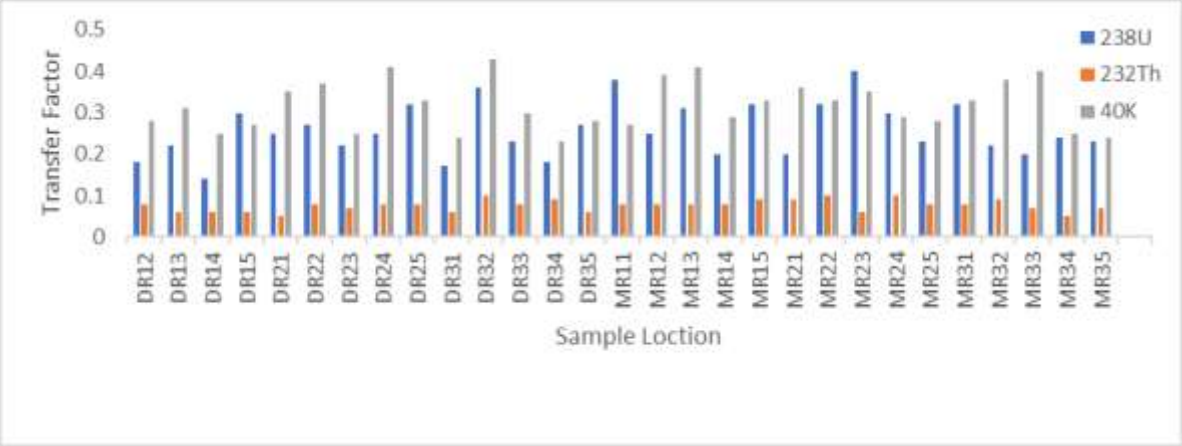

Figure 3: Transfer factor from soil-to-rice plants for the radionuclides ^{238}U, ^{232}Th, and ^{40}K in Dukku and Maurida Farmlands.

4 DISCUSSION

4.1 Radionuclide activity concentration in soil and rice.

To determine the radionuclide activity concentrations (RAC) of ^{238}U, ^{232}Th, and ^{40}K, soil and rice samples collected from Birnin Kebbi were analysed using a NaI(Tl) detector. Tables 3 and 4 present the measured RAC values of soil and corresponding rice samples which showed appreciable variations across the sampling locations, with their distribution and variability illustrated in Figure 1 and 2. Table 3 represents RAC of soil with the calculated mean RAC (± standard error) to be 14.60±1.11Bqkg^{-1} for ^{238}U, 21.47±1.55Bqkg^{-1} for ^{232}Th, and 328.60±12.92Bqkg^{-1} for ^{40}K, with the concentrations being lower than the world average values of 35, 30 and 400Bqkg^{-1}respectively (UNSCEAR, 2000).The analysis confirms the presence of all three radionuclides at significant in all sample. However, as shown in Figure 1, the distribution varied, with RAC varying substantially both within and between the sampled areas. The highest ^{238}U RAC of 19.21±1.71Bqkg^{-1} was measured in soil sample MS35 from Maurida3, while the lowest 10.15±0.58Bqkg^{-1} was found in sample MS23 from Maurida2. For ^{232}Th, the minimum value of 13.86±1.01Bqkg^{-1} was recorded in sample MS11 from Maurida1, and the maximum value of 34.00±2.23Bqkg^{-1} was obtained from sample MS34 in Maurida3. For ^{40}K, RAC ranged from a minimum of 176.60±7.06Bq kg^{-1} in sample MS33, Maurida3 to a maximum of 510.21±20.41Bqkg^{-1} from DS23 sample in Dukku2.

This study varies from previous literatures (Alsaffar *et al.*,2015; Ocheje and Tyovenda ,2020; Ugbede *et al.*,2021) in which it was higher than the world limits but agrees with the results gotten by (Ehsan., *et al.*2019; Avvwiri. and Agbalagba, 2013; Proshaad *et al*,.2019) which was lower than the permissible limits.

The mean radium equivalent assessed from the RAC of radionuclides in soil samples was 77.07Bqkg^{-1}. These values are lower than the acceptable limits of 370Bqkg^{-1} (UNESCA,2000). The radium equivalent results attained in this study agrees to the values obtained by (Mgbeokwere.C.2023). Table 5 displays the radiation dose and hazard indices of soil samples from the study areas, the absorbed gamma dose rate (DR) for the soil samples ranged from 24.49 to 53.52nGyh^{-1}, with a mean value of 35.18nGyh^{-1}, which is lower than the recommended global average limit of 59nGyh^{-1}. The annual effective dose equivalent (AEDE) varied between 0.03 and 0.07mSvy^{-1}, with an average of 0.04mSvy^{-1}, remaining well below the ICRP public exposure limit of 1.00 mSvy^{-1}. The excess lifetime cancer risk (ELCR ×10^{-3}) ranged from 0.10 to 0.23 ×10^{-3}, with an average value of 0.15×10^{-3} which is lower than the ICRP reference value of 0.29 ×10^{-3}.

The activity utilization index (AUI) recorded values between 0.32 and 0.84, with a mean value of 0.54, which is less than the recommended unity limit (AUI ≤ 1). The annual gonadal dose equivalent (AGDE)

ranged from 160.67 to 388.99μSvy^{-1}, with an average of 250.30μSvy^{-1}, remaining below the ICRP recommended limit of 300 μSvy^{-1}. The gamma activity index (Iγr) varied from 0.35 to 0.84, with a mean value of 0.54, which satisfies the recommended criterion of Iγ ≤ 1.

The obtained radiological risk parameters are consistent with previously reported studies (Ocheje and Tyovenda ,2020; Ugbede *et al.*,2021), and are significantly lower than values reported in high background radiation areas such as (Mgbeokwere *et al*..,2023). These findings suggest that the soils do not present an immediate radiological health risk; however, protracted exposure may contribute to potential long-term radiological effects.

Similarly, the measured results for rice in table 4 indicated mean RAC of 3.79±0.38, 1.75±0.24 and 97.86±1.61Bqkg^{-1} for ^{238}U, ^{232}Th, and ^{40}K respectively, with the concentrations being lower than the world average values of 35, 30 and 400Bqkg^{-1} respectively (UNESCA,2000). For ^{238}U, the minimum value of 2.69±0.16Bqkg^{-1} was detected from DR13 sample in Dukku1, and the maximum value of 4.96±0.75 Bqkg^{-1} was analyzed from MR31 sample in Maurida3. For ^{232}Th, the minimum value of 1.09±0.17Bqkg^{-1} was assessed from MR35 sample in Maurida3 while the maximum value of 2.98±0.23Bqkg^{-1} was observed from MR11 sample in Maurida1. For ^{40}K, the minimum value of 70.67±1.17Bqkg^{-1} was observed from MR33 sample in Maurida3, while the maximum value of 124.99±2.45Bqkg^{-1} from DR23 sample in Dukku2. These results are consistent with findings from similar studies (Ocheje and Tyovenda *et al.*,2020; Ilemona *et al.*,2016; Mgbeokwere ,2023; Ibikunle *et al.*,2019; Ugbede., *et al.*,2021; Asaduzzaman, 2014) which satisfies the recommended limit with no future radiological health risks on the consumers.

The overall results demonstrate considerable variability in the RAC of these radionuclides. The observed non-uniform levels of RAC in the soil and corresponding rice are likely due to factors including the various geological configuration and essential radionuclide availability of the cultivation soils, their physicochemical properties, the type and quantity of fertilizer applied, the soil-to-rice transfer potential, and the metabolic characteristics of the produce (Shanthia,2013).

Table 6 presents the radiation dose rates and hazard indices for rice samples collected from the study locations. The absorbed dose rate (DR) in these samples ranged from 7.59 to 11.89nGyh^{-1}, with a mean of 10.13nGyh^{-1}, which is below the world average limit of 59nGyh^{-1}. Annual effective dose equivalents (AEDE) ranges between 0.01 and 0.01 mSvy^{-1}, with mean of 0.01mSvy^{-1}, which is noticeably under the ICRP limit of 1.00mSvy^{-1} for public exposure. Excess lifetime cancer risk (ELCR ×10^{-3}) values spanned 0.03 to 0.05 ×10^{-3}, with a mean of 0.05 ×10^{-3}, the values are significantly lower than the ICRP reference level of 0.29 ×10^{-3}. Annual gonadal dose equivalents (AGED) ranged from 52.36 to 82.01μSvy^{-1}, averaging 48.31μSvy^{-1}, the value is within the ICRP recommended limit of 300μSv y^{-1}. Radiation hazard indices agree with the findings similar to (Mgbeokwere *et al*..,2023; Ocheje and Tyovenda. ,2020; Ugbede *et al.*,2021). The findings show that rice consumption poses an insignificant radiological risk, Nonetheless, the long-term, continuous intake of these radionuclides, even at low concentrations, remains a likely concern, since cumulative exposure over time may enhance the prospect of adverse health effects, including cancer. The age-dependent assessment of total annual committed effective dose, presented in Table 7, shows consistently low values across all population groups. The calculated doses ranged from 0.01 to 0.01mSvy^{-1}, with the means of 0.01mSvy^{-1} for infants (<1 year), 0.01-0.02mSv y^{-1} for children (1–7 years) with mean value of 0.02, and 0.02-0.03,0.03-0.04, and 0.03-0.04mSvy^{-1} for the older children, adolescents, and adults (7–12, 12–17, and >17 years) with mean values of 0.03,0.03 and 0.03 respectively. All measured and averaged values fall noticeably below the internationally recognized limit of 1.00 mSvy^{-1}. This pattern of slight dose accretion is consistent with findings reported in similar agricultural settings, such as a study on rice in Malaysia by (Asaduzzaman *et al*.,2015).

Table 8 represent the bioaccumulation factor (BAF) from soil to rice across the study locations, The distribution of these transfer factors is shown in Figure 3. Mean TF of, ^{238}U ^{232}Th and ^{40}K from soil to rice are 0.22, 0.08 and 0.32 respectively. The range of values of ^{238}U ^{232}Th and ^{40}K varies as 0.14 to 0.40, 0.05 to 0.08 and 0.23 to 0.43 respectively. The value of BAF may be influenced by the richness of the organic matter in the soil. The mean transfer factor obtained indicates that the value is less than the world

recommended value of unity and (UNSCEAR, 2000) respectively for ^{238}U ^{232}Th and ^{40}K. These results indicate that the current levels of radionuclide transfer from soil to rice do not pose an immediate radiological health threat to consumers. However, the potential for bioaccumulation of radionuclides and lifelong chronic exposure underscores the importance of continued monitoring to safeguard against possible long-term health risks.

This study provides comprehensive baseline data for natural radionuclides in the soil-rice system of Birnin Kebbi, Kebbi State.The activity radionuclides activity concentration of natural radionuclides in rice and corresponding soil samples collected from (DUKKU and MAURIDA) farmlands were measured using a sodium iodide NaI(Tl) gamma spectrometry**.** Radiological hazard indices were also analyzed based on the measured activity levels. The average activity concentrations in soil for ^{238}U, ^{232}Th, and ^{40}K were 14.60±1.11, 21.47±1.55, and 328.60±12.92Bqkg^{-1} respectively. Similarly, the average activity concentrations in rice sample for ^{238}U, ^{232}Th, and ^{40}K were 3.79±0.38, 1.75±0.24, and 97.86±1.61Bqkg^{-1} respectively, all below international safety thresholds set by UNSCEAR. The mean soil-to-rice transfer factors were 0.22, 0.08, and 0.32 for ^{238}U, ^{232}Th, and ^{40}K, respectively, showing low bioaccumulation factors. The findings indicate that rice consumption from the studied area does not pose a significant radiological health risk to the population All radiological health risk limits fall below their respective safe levels. The findings validate no considerable radiological risk; therefore, maintaining consistent surveillance of soil and rice is advised as a precautionary radiological safety practice.

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