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Assessment of Activity Concentrations and Soil-to-Plant Transfer Factors of Natural Radioactivity in Rice Plant Components grown in Kano State, Nigeria

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ABSTRACT

Transfer Factor (TF) depicts the percentage or fraction of natural radioactivity in the soil that is absorbed by different parts of a plant which are eventually transferred, directly or indirectly, to man during ingestion. Activity concentrations of primordial radionuclides were determined in farm soil and rice plant components (root, stem, leaf and seed) in six Local Government Areas (Bagwai, Bunkure, Dambatta, Garko, Kura and Wudil) renowned for production of rice in Kano State, Nigeria, using gamma-ray spectrometry method with sodium iodide scintillation detector. The mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th were: 509.51, 27.75, and 12.26 Bq.kg^{-1} correspondently in soil; 227.40, 14.24, and 5.19 Bq.kg^{-1} correspondingly in seed; 935.53, 32.73, and 7.29 Bq.kg^{-1} accordingly in leaf; 803.65, 16.72, and 6.76 Bq.kg^{-1} respectively in stem; and, 408.91, 30.03, and 10.31 Bq.kg^{-1} correspondingly in root. The mean concentrations of ^{40}K reported in soil were greater than the world average of 400 Bq.kg^{-1}, while those of ^{238}U and ^{232}Th were less than the world mean values of 35 Bq.kg^{-1} and 30 Bq.kg^{-1} respectively. The estimated mean of TFs of ^{40}K, ^{238}U and ^{232}Th were: 0.52, 0.61, and 0.43 respectively in the seed; 1.95, 1.45, and 0.69 respectively in leaf; 1.72, 0.75, and 0.64 correspondingly in the stem; and, 0.85, 1.27, and 0.76 accordingly in the root. Except for a few plant samples where BDL were recorded for ^{238}U and ^{232}Th, all values of TFs were greater than the recommended values of 4.9 x 10^{-3} and 2.1 x10^{-4} given for ^{238}U and ^{232}Th by the International Atomic Energy Agency in 1993, and 3.0 x 10^{-1} given for ^{40}K by National Council on Radiation Protection in 1991. The higher values of transfer factors recorded in the study areas may be attributed to the geology and farming techniques adopted by rice farmers in Kano State, Nigeria.

Keywords:
Activity concentration,
Soil-to-plant,
Transfer factor,
Natural radioactivity,
Rice plant

INTRODUCTION

Radioactivity is a process through which stability is attained by natural and artificially made unstable elements. Radioactivity can either be of terrestrial or cosmic origin. Every day, radiation from these man-made and natural sources exposes humans to within as well as exterior radiation. Global soil contains different levels of uranium, thorium, and their progenies, which is by far the biggest form of natural radiation exposure. Radionuclide exposure in people can occur through two primary routes: internal and external. The quantum of radionuclides in the soil can influence these major routes either directly or indirectly. When radon gas and its transient daughters enter the human body, they lodge in the respiratory system. Additionally, via an internal gas exchange, radon gas can spread into the bloodstream from the lungs and into the human body, creating an ongoing source of internal exposure to radiation (Ogundele et al., 2021; Ononugbo et al., 2016; Ozdis et al., 2017).

For evaluating radionuclide transport via food chains, the average values of the soil-plant transmit ratio (TF) are widely and normally employed. When evaluating the impacts of radioactive contamination on the environment, one of the most crucial metrics utilized in modelling is soil-plant TF. This metric can be defined as the ratio of radioactivity unit of each dry crop mass to that of level per dry soil mass, taking into account radioactive uptake through the roots (IEAE, 1994). The isotope-binding technique of the soil system affects the Transfer Factor in addition to the type of plant.TF can vary significantly depending on the place, duration after exposure, and season for a given plant type and radionuclide. The physical and chemical characteristics of the soil, ambient factors, and the nuclide's molecular form all affect these changes (Martinez-Aguirre & Perianez, 1998). It is therefore advised to use site-specific data because TF changes depending on the location (IEAE, 1994). Researchers from both inside and outside of Nigeria have studied the soil-to-plant transmission factor of natural radioactivity. Among them are the following academics: Murtadha et al., (2013); Gaffar et al., (2014); Hassan et al., (2010); Wang et al. (1997); Ibikunle et al., (2019); Ononugbo et al., (2019); Alausa, (2020); Aziounu et al., (2021); and other scholars from both inside and outside the nation.

Hence, there is a significant necessity to assess the transfer factors of natural radioactivity from soil to rice plants in Kano. The population in this region heavily relies on cereals (specifically rice and grains) and fruits as their primary food sources. The primary goal is to monitor the exposure of consumers to natural radioactivity resulting from rice ingestion. Simultaneously, this study aims to gather baseline data on the soil-to-plant transfer factors of natural radioactivity, given the lack of existing records in Kano. Therefore, the objective of this research is to determine the concentrations of natural radioactivity in the agricultural soil used for rice cultivation and various components of the rice plant (Seed, Leaf, Stem, and Root). The ultimate aim is to calculate the transfer factors of these foundational radionuclides in the seed, leaf, stem, and root of rice plants grown for consumption by the people of Kano.

MATERIALS AND METHOD

Study locations/areas

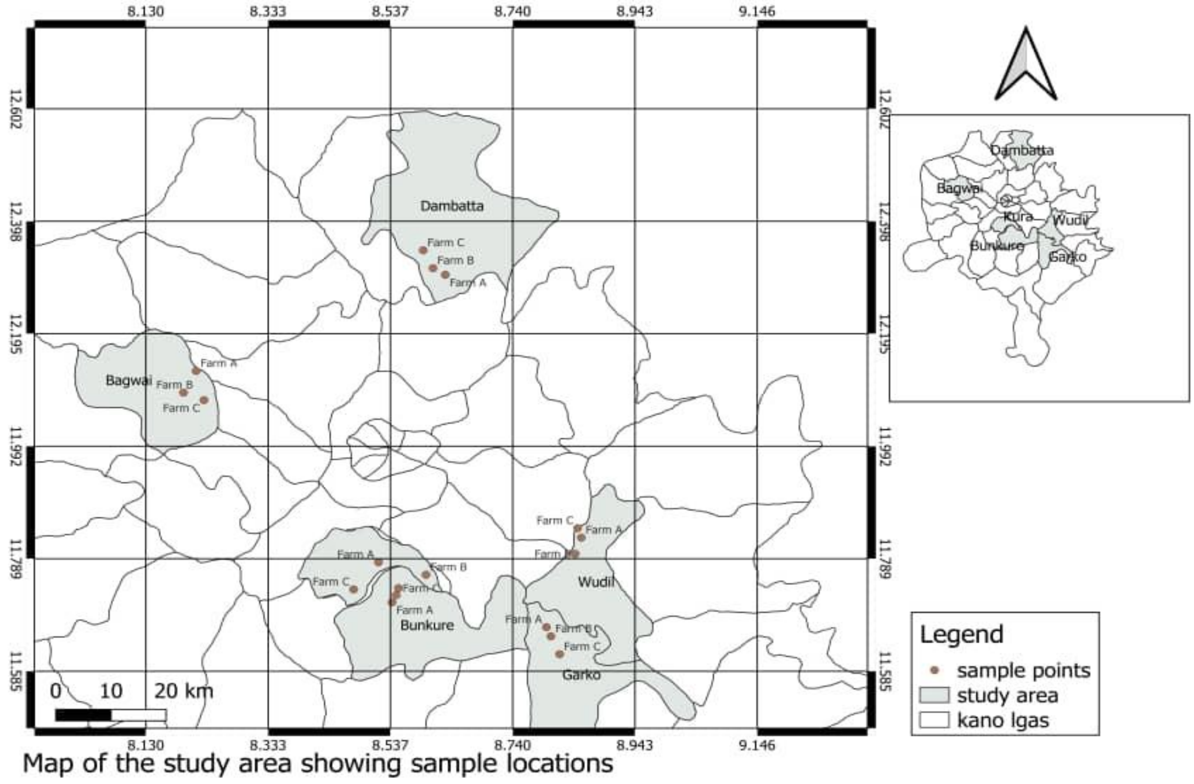

Figure 1: Map of Kano State (Kankara, 2019)

Figure 1 shows the map of Kano State, which is one of the thirty-six (36) States in Nigeria, where this study was conducted. Kano State, situated at an elevation of 481 meters (approximately 1580 feet) above sea level, spans an area of around 20,760 square kilometers. This area encompasses 1,754,200 hectares of agricultural land and over 92,250,081 hectares of forest vegetation and grazing land. Kano is bordered by Katsina State to the west, Kaduna State to the southwest, Jigawa and Bauchi State to the east, and Niger Republic to the north. Geographically, it falls between longitudes 8° 45' E and 12° 05' E and latitudes 10° 30' N and 13° 02' N, placing it within the Sudano-Sahelian zone of Nigeria. Comprising forty-four (44) Local Government Areas, Kano State is further divided into three (3) main regions or senatorial districts: Kano-North, Kano-Central, and Kano-South.

The region predominantly features pre-Cambrian rock of the basement complex, including gneisses, amphibolites, marbles, and older granites, which constitute 80% of Kano State. The Jakara River flows over a crystalline Basement complex of pre-Cambrian origin, extending from Yadai in the north to Gabasawa in the east. The granites in this complex are typically gneissic, often mixed with pegmatite of schist granite and irregular masses of pegmatite.

Aeolian sand, derived from wind deposits, blankets a significant portion of the area, with a thickness of approximately 5 meters in upland regions and 10 meters in lowland plains. Geological structures strongly influence the relief and landforms, creating relatively flat terrain with some undulation, particularly around upstream areas. The region's relief can be categorized into four types: the South and southeastern highlands, the middle and western high plain, the central lowland, and the Chad plain. The highlands cover more than 50% of the Kano Region's surface area, with elevations ranging from 450 meters to 650 meters. (Kankara, 2019; Olofin, 1987).

Collection and Preparation of Samples

A total of ninety (90) study samples were gathered, comprising 18 soil samples and 72 plant samples. The plant samples encompass 18 seed samples, 18 rice leaf samples, 18 rice stem samples, and 18 rice root samples. These samples were collected from 18 farmlands situated across six (6) randomly chosen Local Government Areas (LGAs) out of approximately 13 rice-producing LGAs in Kano State, Nigeria. Collection took place during the harvest in October and November. To ensure cleanliness, plant component samples (leaf, stem, and root) underwent thorough washing to remove soil and other foreign particles. All samples, including soil, seed, leaf, stem, and root, were initially sun-dried for about 7 days and subsequently dried in a temperature-controlled oven at 105°C for 24 hours until a constant weight was achieved. The dried samples were then pulverized into powder form using an Agate mortar and pestle. After crushing, the samples were sieved with a 2 mm mesh sieve to obtain a homogeneous sample (Hossain et al., 2012). Approximately 200 g of each sample (soil and plant) were weighed and transferred into marked, thoroughly cleaned, and uncontaminated cylindrical plastic containers of uniform size. These containers were sealed for four weeks to allow Radon and its short-lived progenies to reach secular equilibrium at ambient temperature before gamma spectroscopy measurements were conducted (Ajayi, 2009; Issa, 2013).

Measurement of Radioactivity of Study samples:

The gamma spectrometric analytical method was employed to measure the activity concentrations of primordial radionuclides in both soil and plant samples. A NaI detector doped with Thallium (model: 802; serial number: 13000850), measuring 76 by 76 mm and housed in a 6 cm thick lead shield lined with Cadmium (Cd) and Copper (Cu) sheets to resist background radiation, was connected to a personal computer-based data acquisition system. This system utilized Genie 2000 (VI.3) software from Canberra through a 16,000 Multi-Channel-Analyzer (MAC). Before analysis, the detector underwent calibration, including energy and efficiency calibrations. Energy calibration involved using different gamma sources of 60Co (1173.2 and 1332.5 KeV), 137Cs (661.9 KeV), and 22Na (511 and 1274 KeV). The resolution of the detector, expressed as the full width at half maximum (FWHM), was directly proportional to the gamma-ray energy (Hossain et al., 2012; Akkurt et al., 2014).

Subsequently, the samples, comprising 18 soil and 72 rice plant component samples, were positioned on the NaI(Tl) detector, each set to a counting time of 29,000 seconds. This duration ensured ample time for the detector to analyze the spectrum with clear and distinct peaks of interest. In NaI(Tl) analysis, the count rates of ^{238}U, ^{232}Th, and ^{40}K in the samples were estimated from the gamma-ray peaks of ^{214}Bi (1.760 MeV), ^{208}Tl (2.615 MeV), and ^{40}K (1.460 MeV) itself, respectively. The count rates under the photo peak of each primordial radionuclide for both detectors were then converted to activity concentration (A) using Equation 1 (Akkurt et al., 2014; Isinkaye & Emelue, 2015):

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

In the provided equation, A represents the activity concentration of the radionuclide within the sample. N corresponds to the net counts or the counting area under the photo peak, $\epsilon\gamma$ denotes the efficiency of the detector for specific γ-ray energy, m signifies the mass of each sample, Iγ represents the intensity of the emitted gamma-ray, and t indicates the counting time.

Estimation of Radium Equivalent Activity and Transfer Factor

Radium Equivalent Activity (Ra$_{eq}$)

Ra$_{eq}$ functions as an index indicator, considering the contribution of each natural radioactivity to the overall dose of the analyzed sample. It is calculated as the weighted sum of the activities of ^{40}K, ^{238}U, and ^{232}Th in the sample under investigation, assuming that 4810 Bq.kg^{-1} of ^{40}K, 370 Bq.kg^{-1} of ^{238}U, and 259 Bq.kg^{-1} of ^{232}Th contribute an equivalent gamma dose rate. The calculation of Ra$_{eq}$ is carried out using Equation 2 (Ajayi, 2009; Srilatha et al., 2015).

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

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

Transfer Factors (TFs)

Transfer factors are commonly used to estimate the transfer of radionuclides within the food chain, serving as a valuable parameter for radiological assessments. The soil-to-plant transfer factor (TF) specifically gauges the transfer of radionuclides from the soil to various plant components, acquired through the plant roots. The calculation of transfer factors for natural radioactivity in the samples is conducted using Equation 3 (Ehlken & Kirchner, 2002; Chibowski & Gladysz, 1999; UNSCEAR, 2000).

$$TF = \frac{Activity\ of\ radionuclide\ in\ plant\ (Bqkg^{-1}\ dry\ weight)}{Activity\ of\ radionuclide\ in\ soil\ (Bqkg^{-1}\ dry\ weight)} \quad (3)$$

RESULTS AND DISCUSSION

Table 1: Activity Concentrations of Natural Radionuclides and Radium Equivalent Activity (Ra_{eq}) in Farm Soil (SLH) in Kano State

LGA	Description	^{40}K (BqKg^{-1})	^{238}U (BqKg^{-1})	^{232}Th (BqKg^{-1})	Ra_{eq} (BqKg^{-1})
Bagwai (BGW)	SLH/BGW 11	544.76 ± 27.18	40.51 ± 3.93	20.16 ± 1.16	111.29
	SLH/BGW 12	504.81 ± 25.08	35.57 ± 3.91	9.29 ± 0.54	87.72
	SLH/BGW 13	373.13 ± 18.66	54.64 ± 5.28	9.01 ± 0.52	96.25
	Range	354.47 - 571.94	31.66 - 59.92	8.49 - 21.32	87.72 - 111.29
	Mean ± STD	**474.23 ± 23.64**	**43.57 ± 4.37**	**12.82 ± 0.74**	**98.42**
Bunkure (BKR)	SLH/BKR 11	519.68 ± 25.00	42.27 ± 4.09	12.73 ± 0.71	100.49
	SLH/BKR 12	525.31 ± 26.13	20.79 ± 2.42	8.63 ± 0.50	73.58
	SLH/BKR 13	484.62 ± 24.04	12.84 ± 1.52	10.91 ± 0.63	65.76
	Range	460.58 - 551.44	11.32 - 46.36	8.13 - 13.44	65.76 - 100.49
	Mean ± STD	**509.87 ± 25.06**	**25.30 ± 2.68**	**10.76 ± 0.61**	**79.94**
Dambatta (DBT)	SLH/DBT 11	484.83 ± 24.09	25.73 ± 2.86	13.00 ± 0.75	81.65
	SLH/DBT 12	551.98 ± 27.44	22.63 ± 2.62	11.94 ± 0.69	82.20
	SLH/DBT 13	383.58 ± 19.04	19.74 ± 2.24	16.06 ± 0.92	72.25
	Range	364.54 - 579.42	17.50 - 28.59	11.25 - 16.98	72.25 - 82.20
	Mean ± STD	**473.46 ± 23.52**	**22.70 ± 2.57**	**13.67 ± 0.79**	**78.70**
Garko (GRK)	SLH/GRK 11	290.60 ± 13.98	19.22 ± 1.49	13.68 ± 0.76	61.16
	SLH/GRK 12	506.90 ± 25.21	38.81 ± 4.12	12.20 ± 0.70	95.29
	SLH/GRK 13	262.15 ± 13.14	48.55 ± 4.96	16.16 ± 0.93	91.85
	Range	249.01 - 532.11	17.73 - 53.51	11.5 - 17.09	61.16 - 95.29
	Mean ± STD	**353.22 ± 17.44**	**35.53 ± 3.52**	**14.01 ± 0.80**	**82.77**
Kura (KUR)	SLH/KUR 11	362.14 ± 18.11	13.89 ± 1.61	3.48 ± 0.20	46.75
	SLH/KUR 12	350.64 ± 17.47	15.34 ± 1.81	5.73 ± 0.33	50.53
	SLH/KUR 13	490.69 ± 24.41	13.59 ± 1.65	6.76 ± 0.39	61.04
	Range	333.17 - 515.10	11.94 - 17.15	3.28 - 7.15	46.75 - 61.04
	Mean ± STD	**401.16 ± 20.00**	**14.27 ± 1.69**	**5.32 ± 0.31**	**52.77**
Wudil (WDL)	SLH/WDL 11	1047.44 ± 51.47	24.23 ± 2.85	15.39 ± 0.88	126.89
	SLH/WDL 12	872.77 ± 43.10	21.43 ± 2.40	12.64 ± 0.73	106.71
	SLH/WDL 13	615.15 ± 30.40	29.72 ± 3.49	22.82 ± 1.31	109.72
	Range	584.75 - 1098.91	19.03 - 33.21	11.91 - 24.13	106.71 - 126.89
	Mean ± STD	**845.12 ± 41.60**	**25.13 ± 2.91**	**16.95 ± 0.97**	**114.44**

Table 2: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th (BqKg^{-1}) in harvested Seed and Leaf of the rice plant in the study areas

	SEED				**LEAF**		
Description	**^{40}K**	**^{238}U**	**^{232}Th**	**Description**	**^{40}K**	**^{238}U**	**^{232}Th**
SDH/BGW 01	224.18 ± 10.81	35.54 ± 2.71	2.45 ± 0.14	LF/BGW 01	1298.07 ± 64.46	38.89 ± 4.52	8.93 ± 0.52
SDH/BGW 02	140.22 ± 7.06	13.08 ± 1.63	0.04 ± 0.003	LF/BGW 02	1220.28 ± 60.50	25.31 ± 2.95	12.38 ± 0.72
SDH/BGW 03	162.54 ± 8.17	10.00 ± 1.11	5.56 ± 0.32	LF/BGW 03	994.77 ± 52.18	32.77 ± 4.58	1.73 ± 0.11
Range	133.16 - 234.99	8.89 - 38.25	0.037 - 5.88	Range	942.59 - 1362.53	22.36 - 43.41	1.62 - 13.10
Mean	**175.65 ± 8.68**	**19.54 ± 1.82**	**2.68 ± 0.15**	**Mean**	**1171.04 ± 59.05**	**32.32 ± 4.02**	**7.86 ± 0.45**

SDH/BKR 01	133.25 ± 6.71	BDL	BDL	LF/BKR 01	929.46 ± 44.71	10.60 ± 0.92	16.52 ± 0.92
SDH/BKR 02	312.25 ± 15.04	3.98 ± 0.33	6.23 ± 0.35	LF/BKR 02	367.19 ± 17.68	57.34 ± 4.42	1.88 ± 0.11
SDH/BKR 03	265.39 ± 13.32	BDL	3.13 ± 0.18	LF/BKR 03	708.08 ± 36.04	11.13 ± 0.77	3.79 ± 0.22
Range	126.54 - 327.29	BDL - 4.31	BDL - 6.58	Range	349.51 - 974.17	9.68 - 61.76	1.77 - 17.44
Mean	**236.96 ± 11.69**	**1.33 ± 0.11**	**3.12 ± 0.18**	**Mean**	**668.24 ± 32.81**	**26.36 ± 2.04**	**7.40 ± 0.42**
SDH/DBT 01	388.81 ± 19.43	33.48 ± 4.10	11.14 ± 0.64	LF/DBT 01	1492.84 ± 74.17	6.46 ± 0.91	7.25 ± 0.42
SDH/DBT 02	185.72 ± 9.34	21.82 ± 2.62	13.56 ± 0.78	LF/DBT 02	1198.86 ± 59.70	65.67 ± 7.49	13.22 ± 0.77
SDH/DBT 03	220.94 ± 10.65	13.37 ± 1.06	7.41 ± 0.41	LF/DBT 03	881.29 ± 47.88	21.35 ± 2.81	BDL
Range	176.38 - 408.24	12.31 - 37.58	7.00 - 14.34	Range	833.41 -1567.01	5.54 -73.16	BDL - 13.99
Mean	**265.16 ± 13.14**	**22.89 ± 2.59**	**10.70 ± 0.61**	**Mean**	**1191.00 ± 60.58**	**31.16 ± 3.74**	**6.82 ± 0.40**
SDH/GRK 01	183.46 ± 9.18	29.73 ± 3.58	11.46 ± 0.66	LF/GRK 01	657.11 ± 32.74	15.78 ± 1.55	6.93 ± 0.40
SDH/GRK 02	210.27 ± 10.13	12.90 ± 1.03	2.25 ± 0.13	LF/GRK 02	879.48 ± 42.30	16.52 ± 1.31	4.36 ± 0.24
SDH/GRK 03	376.78 ± 18.83	8.51 ± 1.06	2.77 ± 0.16	LF/GRK 03	337.51 ± 15.66	27.15 ± 3.02	BDL
Range	174.28 - 395.61	7.45 - 33.31	2.12 - 12.12	Range	321.85 - 921.78	14.23 - 30.17	BDL - 7.33
Mean	**256.84 ± 12.71**	**17.05 ± 1.89**	**5.49 ± 0.32**	**Mean**	**624.70 ± 30.23**	**19.82 ± 1.96**	**3.76 ± 0.21**
SDH/KUR 01	314.37 ± 15.80	BDL	BDL	LF/KUR 01	1018.29 ± 49.01	47.34 ± 3.65	9.90 ± 0.55
SDH/KUR 02	292.41 ± 14.63	14.37 ± 1.81	BDL	LF/KUR 02	1030.75 ± 55.67	48.41 ± 5.58	0.52 ± 0.03
SDH/KUR 03	73.36 ± 3.67	32.47 ± 3.42	7.09 ± 0.41	LF/KUR 03	697.15 ± 32.41	BDL	1.71 ± 0.10
Range	69.69 - 330.17	BDL - 35.89	BDL - 7.50	Range	664.74 - 1396.72	BDL - 53.99	0.49 - 10.45
Mean	**226.71 ± 11.37**	**15.61 ± 1.74**	**2.36 ± 0.14**	**Mean**	**915.40 ± 45.70**	**31.92 ± 3.08**	**4.04 ± 0.23**
SDH/WDL 01	193.57 ± 9.69	5.84 ± 0.81	14.43 ± 0.83	LF/WDL 01	1199.24 ± 59.72	62.46 ± 7.02	26.33 ± 1.52
SDH/WDL 02	180.84 ± 9.11	2.85 ± 0.36	3.02 ± 0.17	LF/WDL 02	1151.42 ± 57.34	68.70 ± 7.91	15.18 ± 0.88
SDH/WDL 03	234.88 ± 11.32	18.41 ± 1.46	2.91 ± 0.16	LF/WDL 03	777.81 ± 37.85	33.22 ± 4.60	BDL
Range	171.73 - 246.20	2.49 - 19.87	2.75 - 15.26	Range	739.96 - 1258.96	28.62 - 76.61	BDL - 27.85
Mean	**203.10 ± 10.04**	**9.03 ± 0.88**	**6.79 ± 0.39**	**Mean**	**1042.82 ± 51.64**	**54.79 ± 6.51**	**13.84 ± 0.80**

Table 3: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th (BqKg^{-1}) in Stem and Root of the rice plant in the study areas

	STEM				**ROOT**		
Description	**^{40}K**	**^{238}U**	**^{232}Th**	**Description**	**^{40}K**	**^{238}U**	**^{232}Th**
ST/BGW 01	1061.40 ± 52.98	55.51 ± 6.91	3.94 ± 0.23	RT/BGW 01	529.76 ± 25.50	56.82 ± 4.41	36.81 ± 2.05
ST/BGW 02	969.50 ± 48.33	6.81 ± 0.85	6.82 ± 0.40	RT/BGW 02	788.33 ± 39.74	12.88 ± 1.69	BDL
ST/BGW 03	794.85 ± 37.41	8.99 ± 1.11	0.23 ± 0.01	RT/BGW 03	401.12 ± 19.91	25.47 ± 3.03	2.99 ± 0.18
Range	757.44 - 1114.38	5.96 - 62.42	0.22 - 7.22	Range	381.21 - 828.07	11.19 - 61.23	BDL - 38.86
Mean	**941.92 ± 46.24**	**23.77 ± 2.96**	**3.66 ± 0.21**	**Mean**	**573.07 ± 28.38**	**31.72 ± 3.04**	**13.27 ± 0.74**
ST/BKR 01	580.62 ± 29.00	BDL	20.33 ± 1.17	RT/BKR 01	668.80 ± 33.53	19.66 ± 2.40	21.38 ± 1.23
ST/BKR 02	1066.63 ± 51.31	35.31 ± 2.77	BDL	RT/BKR 02	351.83 ± 17.60	51.84 ± 5.56	17.18 ± 0.99
ST/BKR 03	700.20 ± 38.97	11.72 ± 0.74	1.28 ± 0.09	RT/BKR 03	505.54 ± 24.89	10.51 ± 1.41	3.33 ± 0.21
Range	551.62 - 1117.94	BDL - 38.08	BDL - 21.50	Range	334.23 - 702.33	9.10 - 57.40	3.12 - 22.61
Mean	**782.48 ± 39.76**	**15.68 ± 1.17**	**7.20 ± 0.42**	**Mean**	**508.72 ± 25.34**	**27.34 ± 3.12**	**13.96 ± 0.81**
ST/DBT 01	836.82 ± 40.25	25.18 ± 1.98	20.21 ± 1.13	RT/DBT 01	153.32 ± 7.39	27.30 ± 2.14	11.04 ± 0.62
ST/DBT 02	1125.87 ± 54.14	22.90 ± 1.80	8.97 ± 0.50	RT/DBT 02	357.26 ± 17.21	22.65 ± 1.87	6.16 ± 0.34
ST/DBT 03	605.75 ± 29.88	15.21 ± 1.81	0.17 ± 0.01	RT/DBT 03	197.64 ± 8.89	13.42 ± 1.13	4.45 ± 0.28
Range	575.87 - 1180.01	13.40 - 27.16	0.16 - 21.34	Range	145.93 - 374.47	12.29 - 29.44	4.17 - 11.66
Mean	**856.15 ± 41.42**	**21.10 ± 1.86**	**9.78 ± 0.55**	**Mean**	**236.07 ± 11.16**	**21.12 ± 1.71**	**7.22 ± 0.41**
ST/GRK 01	580.64 ± 28.98	7.35 ± 0.95	13.76 ± 0.79	RT/GRK 01	783.85 ± 39.42	76.37 ± 8.25	7.43 ± 0.43
ST/GRK 02	1417.01 ± 70.33	7.71 ± 0.91	2.34 ± 0.14	RT/GRK 02	496.66 ± 24.82	41.23 ± 4.99	5.45 ± 0.32
ST/GRK 03	466.33 ± 22.57	8.03 ± 0.97	17 87 ± 0.95	RT/GRK 03	202.73 ± 10.44	25.61 ± 2.10	4.98 ± 0.30
Range	443.76 - 1487.34	6.40 - 9.00	2.20 - 18.82	Range	192.29 - 823.27	23.51 - 84.62	4.68 - 7.86
Mean	**821.33 ± 40.63**	**7.70 ± 0.94**	**11.32 ± 0.63**	**Mean**	**494.41 ± 24.89**	**47.74 ± 5.11**	**5.95 ± 0.35**
ST/KUR 01	772.27 ± 38.55	10.69 ± 1.67	8.14 ± 0.47	RT/KUR 01	105.64 ± 5.09	5.52 ± 0.47	1.98 ± 0.11

ST/KUR 02	877.98 ± 43.88	30.36 ± 3.69	3.97 ± 0.23	RT/KUR 02	116.32 ± 5.92	8.62 ± 0.81	1.27 ± 0.07
ST/KUR 03	699.31 ± 36.01	20.31 ± 1.16	2.98 ± 0.16	RT/KUR 03	178.75 ± 8.64	47.81 ± 5.11	0.97 ± 0.02
Range	663.30 - 921.86	9.02 - 34.05	2.82 - 8.61	Range	100.55 - 187.39	5.05 - 52.92	0.95 - 2.09
Mean	**783.19 ± 39.48**	**20.45 ± 2.17**	**5.03 ± 0.29**	**Mean**	**133.57 ± 6.55**	**20.65 ± 2.13**	**1.41 ± 0.07**
ST/WDL 01	388.28 ± 16.68	21.54 ± 1.65	2.56 ± 0.14	RT/WDL 01	620.32 ± 29.86	28.17 ± 2.20	34.26 ± 1.91
ST/WDL 02	944.33 ± 45.44	BDL	5.09 ± 0.28	RT/WDL 02	503.44 ± 25.15	48.82 ± 5.28	10.42 ± 0.60
ST/WDL 03	577.90 ± 27.99	13.31 ± 0.81	3.03 ± 0.20	RT/WDL 03	399.17 ± 19.04	17.87 ± 2.35	12.21 ± 0.63
Range	371.60 - 989.77	BDL - 23.19	2.42 - 5.37	Range	380.13 - 650.18	15.52 - 54.10	9.82 - 36.17
Mean	**636.84 ± 30.04**	**11.62 ± 0.82**	**3.56 ± 0.21**	**Mean**	**507.64 ± 24.68**	**31.62 ± 3.28**	**18.96 ± 1.05**

Table 4: Soil-to-plant Transfer factors of ^{40}K, ^{238}U and ^{232}Th in harvested seed and Leaf of the rice plant in the study areas

SEED				**LEAF**			
Description	**^{40}K**	**^{238}U**	**^{232}Th**	**Description**	**^{40}K**	**^{238}U**	**^{232}Th**
SDH/BGW 01	0.412	0.887	0.122	LF/BGW 01	2.383	0.960	0.443
SDH/BGW 02	0.278	0.368	0.004	LF/BGW 02	2.417	0.712	1.333
SDH/BGW 03	0.436	0.183	0.617	LF/BGW 03	2.666	1.035	0.192
Range	0.278 - 0.436	0.183 - 0.887	0.004 - 0.617	Range	2.383 - 2.666	0.712 - 1.035	0.443 - 1.333
Mean	**0.375**	**0.476**	**0.248**	**Mean**	**2.489**	**0.902**	**0.656**
SDH/BKR 01	0.256	BDL	BDL	LF/BKR 01	1.789	0.251	1.298
SDH/BKR 02	0.594	0.191	0.722	LF/BKR 02	0.699	2.758	0.219
SDH/BKR 03	0.548	BDL	0.287	LF/BKR 03	1.461	0.867	0.347
Range	0.256 - 0.594	BDL - 0.191	BDL - 0.722	Range	0.699 - 1.789	0.251 - 2.758	0.219 - 1.298
Mean	**0.466**	**0.064**	**0.336**	**Mean**	**1.316**	**1.292**	**0.621**
SDH/DBT 01	0.802	1.301	0.857	LF/DBT 01	3.079	0.251	0.558
SDH/DBT 02	0.336	0.964	1.136	LF/DBT 02	2.171	2.902	1.107
SDH/DBT 03	0.576	0.677	0.461	LF/DBT 03	2.298	1.082	BDL
Range	0.336 - 0.802	0.677 - 1.301	0.461 - 1.136	Range	2.171 - 3.079	0.251 - 2.902	BDL - 1.107
Mean	**0.571**	**0.981**	**0.818**	**Mean**	**2.516**	**1.412**	**0.555**
SDH/GRK 01	0.631	1.547	0.834	LF/GRK 01	2.261	0.821	0.507
SDH/GRK 02	0.415	0.332	0.184	LF/GRK 02	1.735	0.426	0.357
SDH/GRK 03	1.437	0.175	0.171	LF/GRK 03	1.287	0.559	BDL
Range	0.415 - 1.437	0.175 - 1.547	0.171 - 0.834	Range	1.287 - 2.261	0.426 - 0.821	BDL - 0.507
Mean	**0.828**	**0.685**	**0.396**	**Mean**	**1.761**	**0.602**	**0.288**
SDH/KUR 01	0.868	BDL	BDL	LF/KUR 01	2.812	3.408	2.845
SDH/KUR 02	0.834	0.937	BDL	LF/KUR 02	2.940	3.156	0.091
SDH/KUR 03	0.150	2.389	1.049	LF/KUR 03	1.421	BDL	0.253
Range	0.150 - 0.868	BDL - 2.389	BDL - 1.049	Range	1.421 - 2.940	BDL - 3.408	0.091 - 2.845
Mean	**0.617**	**1.109**	**0.350**	**Mean**	**2.391**	**2.188**	**1.063**
SDH/WDL 01	0.185	0.241	0.938	LF/WDL 01	1.145	2.578	1.711
SDH/WDL 02	0.207	0.133	0.239	LF/WDL 02	1.319	3.206	1.201
SDH/WDL 03	0.382	0.619	0.128	LF/WDL 03	1.264	1.118	BDL
Range	0.185 - 0.382	0.133 - 0.619	0.128 - 0.938	Range	1.145 - 1.319	1.118 - 3.206	BDL - 1.711
Mean	**0.258**	**0.331**	**0.435**	**Mean**	**1.243**	**2.301**	**0.971**

Table 5: Soil-to-plant Transfer factors ^{40}K, ^{238}U and ^{232}Th in Stem and Root of the rice plant in the study areas

STEM				ROOT			
Description	**^{40}K**	**^{238}U**	**^{232}Th**	**Description**	**^{40}K**	**^{238}U**	**^{232}Th**
ST/BGW 01	1.948	1.370	0.915	RT/BGW 01	0.972	1.403	1.826
ST/BGW 02	1.912	0.191	0.734	RT/BGW 02	1.562	0.362	BDL
ST/BGW 03	2.130	0.165	0.026	RT/BGW 03	1.075	0.466	0.332
Range	1.912 - 2.130	0.165 - 1.370	0.026 - 0.915	Range	0.972 - 1.562	0.362 - 1.403	BDL - 1.826
Mean	**2.000**	**0.575**	**0.558**	**Mean**	**1.203**	**0.744**	**0.719**
ST/BKR 01	1.117	BDL	1.597	RT/BKR 01	1.287	0.465	1.679
ST/BKR 02	2.030	1.698	BDL	RT/BKR 02	0.670	2.494	1.991
ST/BKR 03	1.445	0.909	0.117	RT/BKR 03	1.403	0.819	0.305
Range	1.117 - 2.030	BDL - 1.698	BDL - 1.597	Range	0.670 - 1.403	0.465 - 2.494	0.305 - 1.991
Mean	**1.531**	**0.869**	**0.571**	**Mean**	**1.120**	**1.259**	**1.325**
ST/DBT 01	1.726	0.979	1.555	RT/DBT 01	0.316	1.061	0.849
ST/DBT 02	2.040	1.012	0.751	RT/DBT 02	0.647	1.001	0.516
ST/DBT 03	1.579	0.771	0.011	RT/DBT 03	0.515	0.680	0.277
Range	1.579 - 2.040	0.771 - 1.012	0.011 - 1.555	Range	0.515 - 0.647	0.680 - 1.061	0.277 - 0.849
Mean	**1.782**	**0.921**	**0.772**	**Mean**	**0.493**	**0.914**	**0.547**
ST/GRK 01	1.998	0.382	1.006	RT/GRK 01	2.697	3.973	0.543
ST/GRK 02	2.795	0.199	0.192	RT/GRK 02	0.980	1.062	0.447
ST/GRK 03	1.779	0.165	1.106	RT/GRK 03	0.773	0.527	0.308
Range	1.779 - 2.795	0.165 - 0.382	0.192 - 1.106	Range	0.773 - 2.697	0.527 - 3.973	0.308 - 0.543
Mean	**2.191**	**0.249**	**0.768**	**Mean**	**1.483**	**1.854**	**0.433**
ST/KUR 01	2.133	0.789	2.339	RT/KUR 01	0.292	0.397	0.569
ST/KUR 02	2.504	1.979	0.693	RT/KUR 02	0.332	0.562	0.222
ST/KUR 03	1.425	1.494	0.441	RT/KUR 03	0.364	3.518	0.143
Range	1.425 - 2.504	0.789 - 1.979	0.441 - 2.339	Range	0.292 - 0.364	0.397 - 3.518	0.143 - 0.569
Mean	**2.021**	**1.424**	**1.158**	**Mean**	**0.329**	**1.492**	**0.311**
ST/WDL 01	0.371	0.889	0.166	RT/WDL 01	0.592	1.163	2.226
ST/WDL 02	1.082	BDL	0.403	RT/WDL 02	0.577	2.278	0.824
ST/WDL 03	0.939	0.448	0.133	RT/WDL 03	0.649	0.601	0.535
Range	0.371 - 1.082	BDL - 0.889	0.133 - 0.403	Range	0.577 - 0.649	0.601 - 2.278	0.535 - 2226
Mean	**0.797**	**0.446**	**0.234**	**Mean**	**0.606**	**1.347**	**1.195**

Table 6: Comparison of mean Transfer factors obtained in this study with similar studies within and outside Nigeria

Location/Country	**Plants Part**	**Transfer Factors**				**References**
		^{40}K	**^{238}U**	**^{226}Ra**	**^{232}Th**	
Kano, Nigeria	Seed	0.52	0.61	-	0.43	Present Study
	Leaf	1.95	1.45	-	0.69	
	Stem	1.72	0.75	-	0.68	
	Root	0.87	1.27	-	0.76	
Ufam, Nigeria	Tuber	3.64	1.82	-	0.72	Essien et al., (2021)
Obot Nduo, Nigeria	Tuber	4.18	1.30	-	0.51	
Niger Delta region, Nigeria	Crops	0.58	2.57	-	0.47	Avwiri et al., (2021)
Wukari, Nigeria	Crops	0.40	0.74	-	0.57	Tyovenda et al., (2022)
Jalingo, Nigeria	Crops	0.51	0.27	-	0.10	
Ibadan, Nigeria	Seed	0.27	BDL	-	0.09	Adesiji & Ademola, (2019)
	Leaf	0.93	0.33	-	0.08	
	Stem	1.74	BDL	-	0.29	

	Root	1.29	1.01	-	0.60	
Agege, Nigeria	Grass	0.29	0.88	-	0.80	Ilori & Alausa, (2019)
Kuru-Jos, Nigeria	Seed	0.37	0.31	-	0.19	
	Seed	0.23	0.27	-	0.17	Alausa, (2020)
	Root/tuber	0.39	0.29	-	0.16	
	Root/tuber	0.29	0.33	-	0.13	
Backfors, Sweden		0.60	0.80	0.50	0.60	
Vikdrolet, Sweden		0.60	0.80	0.50	0.80	Pallavicini, (2011)
Mojsjovik (2009), Sweden		4.30	-	1.30	0.30	
Lovstalot, Sweden		0.90	1.60	-	0.40	
Mryviken, Sweden		1.60	1.70	0.70	0.90	
Skogsvallen, Sweden		0.50	-	1.00	-	
Hallen, Sweden		1.30	-	-	-	
Klins, Egypt		2.30	2.00	-	1.20	Fawzia et al., (2017)
Outside Klins, Egypt		0.04	0.06	-	0.05	
Inshas city, Egypt		0.04	0.07	-	0.05	Mohammed et al., (2016)
Manikganj, Bangladesh		1.58	-	0.25	-	
Savar, Bangladesh		1.63	-	0.40	-	Gaffar et al., (2014)
Chittagong, Bangladesh		0.28	-	0.06	0.89	Chakraborty et al., (2013)
Palestine, Bangladesh		1.70	0.50	0.60	0.31	Jazzar & Thabayneh, (2014)
Qassim, Saudi Arabia		0.16	-	0.12	-	Alhabir & El-Taher, (2013)
Canada		-	-	0.06	0.03	Sheppard et al., (2005)
World Average		**-**	**0.02**	**0.04**	**0.04**	**UNSCEAR, 2010**

Table 1 displays the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th, as well as the Radium equivalent activity (Ra_{eq}) in the agricultural soils within the study regions. The mean activity concentrations of ^{40}K, ^{238}U, and ^{232}Th were as follows: 474.23 ± 23.64, 43.57 ± 4.37 and 12.82 ± 0.74 Bq.kg^{-1} respectively in Bagwai; 509.87 ± 25.06, 11.56 ± 1.34 and 10.76 Bq.kg^{-1} respectively in Bunkure; 473.46 ± 23.52, 22.70 ± 2.57 and 13.67 ± 0.79 Bq.kg^{-1} respectively in Dambatta; 353.22 ± 17.44, 35.53 ± 3.52 and 14.01 ± 0.80 Bq.kg^{-1} respectively in Garko LGA; 401.16 ± 20.00, 14.27 ± 1.69 and 5.32 ± 0.31 Bq.kg^{-1} respectively in Kura; and, 845.12 ± 41.60, 25.13 ± 2.91 and 16.95 ± 0.97 Bq.kg^{-1} respectively in Wudil LGA. Except for Garko LGA, all mean activity concentrations of ^{40}K in the studied locations exceeded the global average of 400 Bq.kg^{-1} (UNSCEAR, 2000). In Bagwai and Garko LGAs, activity concentrations of ^{238}U surpassed the world average of 35 Bq.kg^{-1} (UNSCEAR, 2000), while lower values were observed in other LGAs. Additionally, concentrations of ^{232}Th in farm soils across all sampled locations were below the global average of 30 Bq.kg^{-1}. The average Radium equivalent activity (Ra_{eq}) in the study areas were: 98.42, 66.21, 78.70, 82.77, 52.77, and 114.44 Bq.kg^{-1} in Bagwai, Bunkure, Dambatta, Garko, Kura, and Wudil, respectively. These values fall below the world permissible limit of 370 Bq.kg^{-1} (UNSCEAR, 2000).

Table 2 displays the natural radioactive activity concentration in the harvested rice leaves and seeds in the locations under investigation. According to the analysis's findings, the mean activity quantities of ^{40}K, ^{238}U, and ^{232}Th were: 175.65 ± 8.68, 19.54 ± 1.82, and 2.68 ± 0.15 Bq.kq^{-1} respectively in Bagwai; 236.96 ± 11.69, 1.33 ± 0.11, and 3.12 ± 0.18 Bq.kg^{-1} respectively in Bunkure: 265.16 ± 13.14, 22.89 ± 2.59, and 10.70 ± 0.61 Bq.kg^{-1} correspondingly in Dambatta; 256.84 ± 12.71, 17.05 ± 1.89, and 5.49 ± 0.32 Bq.kg^{-1} respectively in Garko LGA; 226.71 ± 11.37, 15.61 ± 1.74, and 2.36 ± 0.14 Bq.kg^{-1} correspondingly in Kura; and, 203.10 ± 10.04, 9.03 ± 0.88, and 6.79 ± 0.39 Bq.kg^{-1} correspondingly in Wudil LGA. The maximum values of activity concentrations of ^{40}K, ^{238}U and ^{232}Th recorded in harvested seed in the study were: 388.81, 35.54, and 14.43 Bq.kg^{-1} respectively, and the minimum were: 73.36 Bq.kg^{-1}, BDL, and BDL respectively.

In rice leaf component, the mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th obtained from the analytical results were: 1171.04 ± 59.05, 32.32 ± 4.02, and 7.86 ± 0.45 Bq.kg^{-1} respectively in Bagwai; 668.24 ± 32.81, 26.36 ± 2.04, and 7.40 ± 0.42 Bq.kg^{-1} respectively in Bunkure; 1191.00 ± 60.58, 31.16 ± 3.74, and 6.82 ± 0.40 Bq.kg^{-1} respectively in Dambatta; 624.70 ± 30.23, 19.82 ± 1.96, and 3.76 ± 0.21 Bq.kg^{-1} respectively in Garko LGA; 915.40 ± 45.70, 31.92 ± 3.08, and 4.04 ± 0.23 Bq.kg^{-1} correspondingly in Kura; and, 1042.82 ± 51.64, 54.79 ± 6.51, and 13.84 ± 0.80 Bq.kg^{-1} respectively in Wudil LGA. The maximum values of activity concentrations of ^{40}K, ^{238}U and ^{232}Th obtained in rice leaf component were: 1492.84, 68.70 and 26.33

Bq.kg^{-1} correspondingly, while the minimum was: 337.51 Bq.kg^{-1}, BDL and BDL respectively.

Table 3 displays the activity of high levels of primordial radionuclides in the rice plant's stem and root sections within the designated study locations. In the rice stem component, the average activity the levels of ^{40}K, ^{238}U, and ^{232}Th were as follows: 941.92 ± 46.24, 23.77 ± 2.96, and 3.66 ± 0.21 Bq.kg^{-1} correspondingly in Bagwai; 782.48 ± 39.76, 15.68 ± 1.17, and 7.20 ± 0.42 Bq.kg^{-1} correspondingly in Bunkure; 856.15 ± 41.42, 21.10 ± 1.86, and 9.78 ± 0.55 Bq.kg^{-1} respectively in Dambatta; 821.33 ± 40.63, 7.70 ± 0.94, and 11.32 ± 0.63 Bq.kg^{-1} respectively in Garko; 738.19 ± 39.48, 20.45 ± 2.17, and 5.03 ± 0.29 Bq.kg^{-1} in Kura; and, 636.84 ± 30.04, 11.62 ± 0.82, and 3.56 ± 0.21 Bq.kg^{-1} correspondingly in Wudil LGA. The maximum values of activity concentrations of ^{40}K, ^{238}U and ^{232}Th obtained in stem components in all the study locations were 1417.01, 55.51 and 20.33 Bq.kg^{-1} respectively, while minimum values of 388.28 Bq.kg^{-1}, BDL and BDL were recorded respectively.

Also, the mean activity concentrations of ^{40}K ^{238}U and ^{232}Th obtained in rice root component were: 573.07 ± 28.38, 31.72 ± 3.04, and 13.27 ± 0.74 Bq.kg^{-1} correspondingly in Bagwai; 508.72 ± 25.34, 27.34 ± 3.12, and 13.96 ± 0.81 Bq.kg^{-1} respectively in Bunkure; 236.07 ± 11.16, 21.12 ± 1.71, and 7.22 ± 0.41 Bq.kg^{-1} respectively in Dambatta; 494.41 ± 24.89, 47.74 ± 5.11, and 5.95 ± 0.35 Bq.kg^{-1} respectively in Garko; 133.57 ± 6.55, 20.65 ± 2.13, and 1.41 ± 0.67 Bq.kg^{-1} in Kura; and, 507.64 ± 24.68, 31.62 ± 3.28, and 18.96 ± 1.05 Bq.kg^{-1} in Wudil LGA of Kano, Nigeria. The highest values of concentrations of ^{40}K, ^{238}U and ^{232}Th recorded in the root component of rice plants in the study areas were: 788.33, 76.37 and 36.81 Bq.kg^{-1} correspondingly and the lowest values were: 105.64, 5.52 Bq.kg^{-1} and BDL correspondingly. The activity concentrations of natural radioactivity were generally high in rice leaf component.

For the rice seed and leaf gathered in this investigation, Table 4 displays the natural radioactivity transfer factor from agricultural soil. In Bagwai, an average soil-to-seed (rice) transmit factors (TFs) of ^{40}K, ^{238}U, and ^{232}Th were, correspondingly, 0.375, 0.476, and 0.248; 0.466, 0.064, and 0.336 respectively in Bunkure; 0.571, 0.981, and 0.818 correspondingly in Dambatta; 0.828, 0.685, and 0.396 respectively in Garko; 0.617, 1.109, and 0.350 respectively in Kura; and 0.258, 0.331, and 0.435 correspondingly in Wudil. The minimum and maximum values of TFs recorded for ^{40}K, ^{238}U and ^{232}Th in harvested rice seed samples were: 0.150 and 1.437; BDL and 2.389; and, BDL and 1.136 respectively. International Atomic Energy Agency (IAEA, 1993; Avwiri et al., 2021) recommended that the normal values of transfer factors of ^{226}Ra (or ^{238}U) and ^{232}Th in root, vegetables, fruits and grains for human consumption are 4.9 x 10^{-3} and 2.1 x 10^{-4} correspondingly, while that of ^{40}K is 3.0 x 10^{-1} (NCRP, 1991; Avwiri et al., 2021). The geology of the study areas, farming practices, use of fertilizer/manure, and solubility of the radionuclide in a particular type of soil are all contributing factors to the TFs of the natural radioactivity estimated in the seed samples being greater than the recommended values (Avwiri et al., 2021; Ononugbo et al., 2019; Shyamal et al., 2013). For the rice plant in Bagwai, the calculated average soil-to-leaf transfer factors (TFs) were 2.489, 0.902, and 0.656 for ^{40}K, ^{238}U, and ^{232}Th, respectively; 1.316, 1.292, and 0.621 respectively in Bunkure LGA of Kano State, Nigeria; 2.516, 1.412, and 0.555 respectively in Dambatta; 1.761, 0.602, and 0.288 respectively in Garko; 2.391, 2.188, and 1.063 respectively in Kura; and, 1.243, 2.301, and 0.971 in Wudil LGA. The minimum TF values recorded in leaf samples for ^{40}K, ^{238}U and ^{232}Th were: 0.699, BDL, and BDL; while the maximum values obtained were: 3.079, 3.408 and 2.845 respectively. All the estimated values of TFs of ^{40}K, ^{238}U and ^{232}Th in rice leaf component, except locations where BDL were recorded, were greater than normal/recommended TF values of 3.0 x 10^{-1} (NCRP, 1991), 4.9 x 10^{-3} and 2.1 x 10^{-4} (IAEA, 1993).

Table 5 presents the calculated values of TFs from soil to rice stem and root components of primordial radionuclides in the study areas. The mean values of soil-to-stem rice plant components obtained in the study areas for ^{40}K, ^{238}U and ^{232}Th were: 2.000, 0.575, and 0.318 respectively in Bagwai; 1.531, 0.869, and 0.571 respectively in Bunkure; 1.782, 0.921, and 0.772 respectively in Dambatta LGA; 2.191, 0.249, and 0.768 in Garko LGA; 2.021, 1.424, and 1.158 in Kura: and 0.797, 0.446, and 0.234 in Wudil LGA of Kano State, Nigeria. The highest values of TF from soil to plant/stem recorded in the study areas were; 2.795 (^{40}K), 1.979 (^{238}U) and 2.339 (^{232}Th) and the lowest values include 0.371, BDL, and BDL for ^{40}K, ^{238}U and ^{232}Th respectively. All these values except for BDLs are greater than the normal TFs of ^{238}U and ^{232}Th in roots, vegetables, fruits and grains for human consumption, which are 4.9 x 10^{-3} and 2.1 x 10^{-4} (IAEA, 1993; Avwiri et al., 2021) respectively, and that of ^{40}K which is 3.0 x 10^{-1} (NCRP, 1991; Avwiri et al., 2021). The average values of TFs of ^{40}K, ^{238}U and ^{232}Th from soil-to-rice root component were: 1.203, 0.744, and 0.719 respectively in Bagwai; 1.000, 1.259, and 1.325 respectively, in Bunkure; 0.493, 0.914, and 0.547 correspondingly in Dambatta; 1.483. 1.854, and 0.433 respectively in Garko; 0.329, 1.492, and 0.311 correspondingly in Kura LGA; and, 0.606, 1.357, and 1.195 accordingly in Wudil LGA, Kano State, Nigeria.

Table 6 compares the values of TFs obtained in this study with values in similar studies by scholars. The maximum mean value of TF of ^{40}K reported in this study, 1.95 was recorded in the leaf component of rice plant, this is lower than those reported earlier by (Essien *et al*., 2021; Pallavicini, 2011 and Fawzia *et al*., 2017), but lower than values recorded by other scholars. Additionally, the rice plant's leaf component in the research locations had an equally calculated maximum mean value of 238U (1.45), but this value was less than that of previous reports by (Essien et al., 2021; Avwiri et al., 2021; Pallivicini, 2011; and Fawzia et al., 2017). The rice plant's root, however, had the greatest TF value of 232Th (0.76), which is also less than the values previously reported by (Ilori & Alausa, 2019; Pallivicini, 2011 and Fawzia et al., 2017). Every TF value found in the present research and by other researchers in related investigations exceeded the global average values of 0.02 (^{238}U), 0.04 (^{226}Ra) and 0.04 (^{232}Th) respectively (UNSCEAR, 2010). In addition, except for a few farm sites where BDL were recorded, all other sites have their TFs values greater than the normal values of transfer factors of ^{40}K, ^{238}U and ^{232}Th which are: 3.0 x 10^{-1} (NCRP, 1991; Avwiri et al., 2021), 4.9 x 10^{-3} and 2.1 x 10^{-4} (IAEA, 1993; Avwiri et al., 2021) respectively for roots, vegetables, fruits and grains meant for human consumption.

CONCLUSION

The study's Transmission Parameters of Natural Radioactivity levels for the various sections of the rice plant were as follows: ^{238}U > ^{40}K > ^{232}Th in Seed; ^{40}K > ^{238}U > ^{232}Th in Leaf and Stem; and, ^{238}U > ^{40}K > ^{232}Th in Root of rice plant in the study areas. Furthermore, the study found that the highest value of the 40K transfer factor was found in Leaf, followed by Stem, Root, and Seed; the largest value of the 238U transfer factor was found in Leaf, subsequently followed by Root, Stem, and Seed; the spread factor of 232Th was found in Root, subsequently followed by Leaf, Stem, and Seed. Except for a small number of plant constituent samples where BDL was noted, every other sample for which particular values for natural radioactivity have been obtained above the global average value of 0.02 for ^{238}U and 0.04 for ^{232}Th; and the normal values of transfer factors of ^{40}K, ^{238}U and ^{232}Th which are: 3.0 x 10^{-1}, 4.9 x 10^{-3} and 2.1 x 10^{-4} respectively for roots, vegetables, fruits and grains meant for human consumption. This has been attributed to the geology of farm sites, farming techniques and the use of manure (or fertilizers) to boost the yield in these farms.

REFERENCES

Adesiji, N. E. and Ademola, J. A (2019). Soil-to-maize transfer factor of Natural Radionuclides in a tropical Ecosystem of Nigeria. *Nigeria Journal of Pure and Applied Physics*, 9(1): 6 – 10. https://dx.doi.org/10.4314/njpap.v9i1.2

Ajayi, O. S. (2009). Measurement of activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th for assessment of radiation hazards from soils of Southwestern region of Nigeria. *Radiation and Environmental Biophysics*, 48: 323 – 332.

Akkurt, I., Gunoglu, K. and Arda, S. S. (2014). Detection Efficiency of NaI(Tl) Detector in 511 1332 KeV Energy Range. 2104(2014): 186788. pp. 5.

Alausa, S. K. (2020). Radiometric Assessment of farm soils and food crops grown in Kuru- Jos, Nigeria. *Iran J. Med. Phys*., 17(5): 289 – 297. Doi: 10.22038/ijmp.2019.42643.1633

Alharbi, A. and El-Taber, A. (2013). A study of the transfer factor of radionuclides from soil to plant. *Life Science Journal*, 10(2): 532 – 539.

Avwiri, G. O., Ononugbo, C. P. and Olasoji, J. M. (2021). Radionuclide transfer factors of Staple foods and its health risks in Niger Delta region of Nigeria. *Int. J. Innovative Environ. Studies Res.* 9(1): 23 – 32. ISSN: 2354-2918. www.seahipaj.org

Azionu, K. C., Avwiri, G. O. and Ononugbo, C. P. (2021). Radiological health hazards Indices, assessment of natural radioactivity and soil-to-plant transfer factors in selected Crude oil production pipes storage locations in Niger Delta region of Nigeria. *Global Scientific Journal*, 9(5): 253 – 272. ISSN 2320-9186. www.globalscientificjournal.com

Chakraborty, S. R., Azim, R., Rahman, A. K. M. R., and Sarker, R. (2013). Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and plants in the Chittagon city of Bangladesh. *Journal of Physical Science*, 21(1): 95 -113.

Chibowski, S. and Gladyzs A. (1999). Examination of radioactive contamination in the soil-plant system and their transfer to selected animal tissues. *Polish J. Environ, Stud*., 8: 19 – 23.

Ehlken, S. and Kirchner, G. (2002). Environmental process affecting plant root uptake of Radioactive trace elements and variability of transfer factor data: A review. *Journal of Environmental Radioactivity*, 58: 97-112.

Essien, I., Akankpo, A., Nyong, A. and Inyang, E. (2021). Determination of Activity concentrations and soli-to-cassava transfer factors of natural radionuclides in Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria. *Journal of Geography, Environment and Earth Science International* (JGEESI), 25(7): 28-35.

Fawzia, M., Mohammed, E. and Enas, S. (2017). Activity concentration and soil-to-plant Transfer factor of narurally occurring radionuclides around Charcoal Kilns in Egypt. *World Appl. Sci. J.*, 35(11): 2341 – 2347.

Gaffar, S., Ferdous, M. J., Begum, A. and Ullah, S. M. (2014). Transfer of natural radionuclides from soil to Plants in North Western parts of Dhaka. *Malaysian Journal of Soil Science*, 18: 61 – 74.

Hassan, M. K., Zahid, S. C., Muhammad, I. and Khalid, K. (2010). Assessment of radionuclides, trace metals and radionuclide transfer from soil to food of Jhangar valley (Pakistan) using Gamma Ray spectrometry. *Water Air Soil Pollute*, 213; 353 -362.

Hossain, I., Sharip, N., and Viswannathan, K. K. (2012). Efficiency and resolution of HPGe and NaI(Tl) detectors using gamma-ray spectroscopy. *Scientific Research and Essays*. 7(1): 86 89. doi:10.5897/SRE11.1717.

Ibikunle. S. B., Arogunjo, A. M. and Ajayi, O. S. (2019). Characterization of radiation dose Soil-to-plant transfer factor of natural radionuclides in some cities from South-Western Nigeria and its effects on man. *Journal of Scientific African*, 3(2019): 1-10.

Ilori, A. O. and Alausa, S. K. (2019). Estimation of natural radionuclides in grasses, soils, and Cattle –dungs from a Cattle rearing-field at Mangoro-Agege, Lagos State. Nigeria. *FUW Trends in Science and Technology Journal*, 4(1): 18 – 24. e-ISSN: 24085162

International Atomic Energy Agency IEAE, (1993). Isotope Technique in the study of past and current Environmental changes in the Hydrosphere and atmosphere. Proceedings of a symposium, Vienna, 19th – 23rd April, 1993.

International Atomic Energy Agency IAEA, (1994). Handbook of parameter values for predicting of radionuclide transfer in temperate environments technical report Series no. 364 Vienna.

Isinkaye, M. O. and Emelue, H. U. (2015). Natural radioactivity measurements and evaluation of radiological hazards in sediment of Oguta Lake, South-East Nigeria. *Journal of Radiation and Applied Sciences*. 8: 459 – 469. doi.org/10.1016/j.jrras.2015.05.001.

Issa, S. A. M. (2013). Radiometric assessment of natural radioactivity levels of agricultural soil samples collected in Dakahlia, Egypt. *Radiation Dosimetry*, 56(1); 59 – 67.

Jazzar, M. M. and Thabayneh, K. M. (2014). Transfer on natural radionuclides from soil to plants and grass in the Western North of West Bank environment-Palestine. *International Journal of Environmental Monitoring and Analysis*, 2(5): 252 – 258.

Kankara, I. A. (2019). Ground and surface water potentials and accessibility in Kano Municipal, Nigeria: Implication for Geological constraints. *Annals of Geographical Studies*, 2(1): 1-7.

Martinez-Aguirre, A. and Perianez, R. (1998). Soil to plant transfer of ^{226}Ra in a mash area: Modelling Application. *Journal of Environmental Radioactivity*, 39(2): 199 – 213.

Mohammed, E., Fawzia, M., Omar, H, A., Nassif, A. Mansour, E. S. and Noura, M. (2016). Determination of soil-Plant transfer factor of edible plants grown on a contaminated soil with Europium-152. *Middle-East Journal of Scientific Research*, 24(10): 3278 – 3283.

Murtadha, S. A., Mohamad, S. and Sabar, B. (2013). Assessment of radionuclide transfer from soil to vegetables in farms from Cameron Highlands and Penang (Malaysia) Using neutron activation analysis. *Appl. Phys. Res*., 5: 85 – 92.

National Council on Radiation Protection and Measurements NCRP, (1991). Effects of Ionizing Radiation on Aquatic organisms. Report No. 109.

Ogundele, L. T., Oladotun O. A., Abimbola C. O. ans Samuel, I. O. (2021). Heavy metals, radionuclides activity and mineralogy of soil samples from an artisanal gold mining site in Ile-Ife, Nigeria: implications on human and environmental health. *Environmental Health Sciences*, 80(2): 1 – 15.

Olofin, E. A. (1987). Some aspects of physical Geography of Kano region and related human response. Department of Geography Lecture note Series, 1. Bayero University, Kano, Nigeria.

Ononugbo, C. P. and Mgbemere, C. J. (2016). Dose rate and annual effective dose Assessment of terrestrial gamma radiation in Notre fertilizer plant, Onne, Rivers State, Nigeria. *International Journal of Emerging Research in Management and Technology*, 5(9): 30-35.

Ononugbo, C. P., Azikiwe, O. and Avwiri, G. O. (2019). Uptake and distribution of Natural radionuclides in cassava crops from Nigerian Government farms.

Journal of Scientific Research and Reports, 23(5): 1-15 DOI: 10.9734/JSRR/2019/v23i530130

Özdiş, B. E., Çam, N. F. and Canbaz Öztűrk, B. (2017). Assessment of natural radioactivity in cements used as building materials in Turkey. *Journal of Radioanalytical and Nuclear Chemistry*, 311(1): 307 – 16.

Pallavicini, N. (2011). Activity concentration and transfer factors of natural and artificial Radionuclides in the Swedish counties of Uppsala and Jamtland. Master's Thesis, Swedish University of Agricultural Sciences, Department of soil and Environment.

Sheppard, S. C., Sheppard, M. I., Ilin, M. and Thompson P. (2005). Soil-to-plant transfer of Uranium series radionuclides in natural and contaminated settings. *Radioprotection Suppl.*, 1(40): 253- s259.

Shyamal, C. R., Azim, A. K. M., Rahman, and Sarker, (2013). Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and plant in the Chittagong city of Bangladesh. *Journal of Physical Sciences*, 24(1): 95 – 113.

Srilatha, M. C., Rangaswamy, D. R. and Sannappa, J. (2015). Measurement of natural radioactivity and radiation hazard assessment of in the soil samples of Ramanagara and Tumkur Districts, Karnataka, India. *Journal of Radioanalytical and Nuclear Chemistry*, 303: 993 – 1003.

Tyovenda, A. A., Ocheje, J. A., Terver, S. and Uttah, E. U. (2022). Investigation of the Radiological risk of farmlands and the transfer factors from soil to crop in Jalingo and Wukari Local Government Areas of Taraba State, *Nigeria. Journal of Environmental Protection*, 13(2022): 1 – 14.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR, (2000). Exposures from natural radiation sources. Report to the General Assembly, with Annexes, Annex-B, United Nations, New York.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR, (2010). "Sources and Effects of Ionizing Radiation" United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008), vol. 1. United Nations, New York, Annex B: Exposures from Natural Radiation Sources and Annex D: Medical radiation Exposures.

Wang, C. J., Lai, S. Y., Wang, J. J. and Lin, W. M. (1997). Transfer of radionuclides from soil to Grass in Northern Taiwan. *Appl. Radiat. Isotopes*, 48: 301-3.