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Characterization of radiation dose and soil-to-plant transfer factor of natural radionuclides in some cities from south-western Nigeria and its effect on man

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ABSTRACT

Activity concentrations of natural radionuclides, artificial radiocaesium, and soil-to-plant transfer factor have been evaluated in soils and plant (*Amaranthus hybridus*) samples from eighteen locations in south-western Nigeria with the aid of a co-axial type, High Purity Germanium (HPGe) detector. The mean specific activities of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in the soil samples were 393.73 Bq kg^{-1}, 52.91 Bq kg^{-1}, 76.79 Bq kg^{-1} and 1.44 Bq kg^{-1}, respectively, while the mean specific activities of ^{40}K, ^{226}Ra, and ^{232}Th in plant samples were 3,271.66 Bq kg^{-1}, 25.88 Bq kg^{-1}, and 19.90 Bq kg^{-1}, respectively. ^{137}Cs was found to be below detection limit in the plant samples from all locations of the study area. The radium equivalent concentration, the external and internal hazard indices were estimated, and ranged from 28.47 to 701.53 Bq kg^{-1}, 0.08 to 1.89, and 0.10 to 2.33, with mean values of 191.34 Bq kg^{-1}, 0.52, and 0.66, respectively. The mean soil-to-plant transfer factors for ^{40}K, ^{226}Ra and ^{232}Th were 26.58, 0.62, and 0.39, respectively. The mean absorbed dose and the mean annual outdoor effective dose equivalent in soil samples were 86.44 nGy h^{-1} and 0.1060 mSv y^{-1}, respectively. The mean annual effective dose equivalent for the study area is higher than the world average (0.07 mSv y^{-1}) and international recommended standards of 0.1 mSv y^{-1} recommended by World Health Organization (WHO). The excess lifetime cancer risk (ECLR) ranged from 7.35×10^{-5} to 1.36×10^{-3}, with a mean of 3.71×10^{-4}. This value is higher than the world average of 2.9×10^{-4} reported by United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR. The ELCR is a function of environmental geology and ^{40}K has very high soil-to-plant transfer factor compared to other radionuclides in the samples. Regression analysis showed that there was no linearity in the relationship between activity concentration of radionuclides in soil and in plant. This shows that soil-to-plant transfer factor is not a function of soil radioactivity.

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Introduction

Environmental radionuclides can be transferred into human body through various sources and pathways. Apart from atmospheric release, direct inhalation is the initial source of hazard to human [1,2]. Other sources of exposure of main concern are the radionuclides deposited on soils and on the foliage of crop plants, their uptake by the plant and water contaminations. Generally, terrestrial pathways were found to be of more importance than the aquatic pathways [3].

One of the major environmental pathways that leads to human ingestion of radionuclides is the soil-plant-man pathway. The root uptake of radionuclides and the subsequent translocation to the edible plant parts are being influenced by many factors, such as soil characteristics, plant types, physiological processes in each compartment, competing ions, climatic conditions, physico-chemical form of the radionuclides and agricultural practices [4]. The modelling of the radionuclide uptake by the root is a compromise between availability of input parameter and scientifically based mechanistic approaches [5].

The International Atomic Energy Agency (IAEA) reviewed data on transfer factor for different foods and made a compilation for research purposes (TRS-472, [6] and TECDOC, [7]). In his study of filamentous algae from Jadugida, India, Markose [8] observed an elevated concentration of ^{228}Ra with a transfer factor that ranged from 8×10^2 to 3.1×10^3. He showed that variation in concentration is dependent on the proximity of the sampling location with respect to the tailing and pond effluent or main water streams. The transfer factor value is in agreement with the value (5×10^2–1.0×10^3) obtained from a Uranium mill by Tsivoglue [9].

The evaluation of soil-to-plant transfer factor of ^{238}U, ^{210}Pb, ^{210}Po and ^{40}K, for various agriculture products (Vegetables, fruit trees and beans) in some districts of south-Syria by Al-Masri et al. [10] reveals that transfer factor of radionuclides were higher in leaves than fruits except for ^{40}K where the transfer factor for both leaves and fruits were similar. In their report of soil-to-plant transfer factor estimation, Vandenhove et al. [11] concluded that the transfer factor values were generally about 10-fold lower for ^{232}Th and ^{210}Po than for ^{238}U, ^{226}Ra and ^{210}Pb. The data compiled in the IAEA TRS-472 [6] was sometimes less than 10, and therefore the present data could provide more information about the transfer factors of radionuclides under equilibrium conditions.

Research methodology

Collection of samples

Thirty six (36) samples of *Amaranthus hybridus* plant and soil (18 plant samples and 18 soil samples) were collected from 18 locations from the six States in the south-western Nigeria. The soil directly under the plant was collected after the top soil has been removed to get rid of extraneous materials in accordance to IAEA recommendation [12,13]. The soil and plant samples collected were packaged separately in a cellophane bag, well labelled and taken to the laboratory for processing before preparation for activity concentration analysis.

The sample site was chosen with an objective to cover a wide range of study area in the south-western part of the country, which is an important part of the country because there is a high population density and various industrial/agricultural activities are going on in the area. The determination of fallout Caesium-137 concentration was also done in order to estimate the environmental impact and after-effect of the nuclear accident, which happened in some eastern part of the world. The environment of the study area ranges from the mangrove swamps to the tropical rainforest in a low elevation along the Atlantic coast.

Processing of soil and plant samples and preparation for geometry

The soil samples collected were processed following the standard procedure [14,12,13]. The samples were sieved with 2 mm mesh screen to obtain fine textured version, which were then oven dried at about 110 °C to a constant weight to remove all moisture content in it. The soil samples were weighed before and after the oven drying to obtain the fresh and dry weight of the samples. Each of the dried soil samples were then sealed in a 250 ml plastic bottle, weighed, labelled and kept for 30 days to allow time for secular equilibrium between parent and daughter radionuclides before counting in the hyper pure Germanium detector.

The fresh Plant samples were weighed, oven dried at 110 °C to obtain a constant weight without moisture and then reweighed to obtain the dry weight. The dry plant samples were charred under a low flame before they were completely ashed in a muffle furnace at a temperature of 450 °C to obtain a uniform white ash. The samples were pulverized and sealed in a 250 ml plastic bottle after being weighed and labelled. The ash content in the plants was determined using the expression [15]:

$$AC\ (\%) = \frac{Ash\ wt}{Dry\ wt} \times 100 \tag{1}$$

where *AC* is the ash content, *Ash wt* is the weight of sample after being ashed and *Dry wt* is the weight of sample after drying.

The sealed plant samples (ash) were also kept for 30 days to reach secular equilibrium between parent and daughters before activity concentration analysis was done.

Determination of activity concentration of radionuclides

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the samples were measured using high purity Germanium detector (HPGe) with 38% relative efficiency. The energy resolution of the HPGe detector is 2.1 keV at 1.33 MeV gamma line of ^{60}Co. 16 K multichannel analyser was used to obtain the spectrum, and the analysis was done using GENIE-2k (Canberra Industry) software. Quality assurance reference materials were obtained from IAEA for the efficiency calibration of the detector, while maintaining the geometry of detection by using containers of uniform size and type. After applying Compton corrections [16], the three photopeaks of ^{214}Bi (609.3, 1129.3, and 1764.5 keV) were used to evaluate the activity concentration of ^{226}Ra. One photopeak of ^{228}Ac (911.2 keV) and two photopeaks of ^{208}Tl (583.1 and 2614.5 keV) were used for the evaluation of ^{232}Th while the gamma line of ^{40}K (1460.8 keV) was used to evaluate the activity concentration of ^{40}K [12,13]. The minimum detection levels (MDL) for ^{226}Ra, ^{232}Th, and ^{40}K at 60,000 s counting time and 300 g sample weight were 0.62 Bq kg^{-1}, 2.46 Bq kg^{-1}, and 1.42 Bq kg^{-1}, respectively [17,18].

Estimation of soil-to-plant transfer factor (TF)

IAEA [6] has adopted the methodology outlined in the protocol developed by the Working Group of International Union of Radioecologists [19] for standardizing the rooting depth to define soil to plant transfer factor. A standardized soil layer was adopted in this work. For grass, this soil depth value is 10 cm and for all other crops (including fruit trees) it is assumed as 20 cm. Using IAEA guidelines, the soil-to-plant transfer factor *TF* was estimated as [6]:

$$TF = \frac{C_p}{C_s} \tag{2}$$

where C_p = radionuclide concentration in plant (Bq kg^{-1})and C_s = radionuclide concentration in soil (Bq kg^{-1})

The soil-to-plant transfer factors have been calculated for soil samples analysed for radioactivity to evaluate the rate of migration of radionuclides from soil to the plants in the study area.

Radium equivalent concentration and hazard indices

The radium equivalent ($\mathrm{Ra_{eq}}$) describes the gamma output from different mixtures of the natural radionuclides in a material, and it was calculated using [20].

$$\mathrm{Ra_{eq}} = A_{Ra} + 1.43A_{Th} + 0.077A_K \tag{3}$$

where A_{Ra}, A_{Th} and A_K are specific activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

External hazard index (H_{ex}) gives the assessment of the health risk associated with the emission of gamma radiation by various natural radionuclides, while internal hazard index (H_{in}) estimates the internal exposure of living cell to radon and its progeny [5]. The external and internal hazard indices were calculated using [21,22].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{4}$$

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

Data analysis and dose calculation

Exposure and absorption of radiation at 1 m above the ground containing naturally occurring radionuclide poses radiological hazard to human. The total absorbed dose rate in air, (ADRA or D in nGy h^{-1}) was calculated using [5]

$$D\left(nGyh^{-1}\right) = 0.042A_K + 0.462A_U + 0.604A_{Th} \tag{6}$$

where A_K, A_U, and A_{Th} are the specific activities (in Bq kg^{-1}) for ^{40}K, ^{238}U and ^{232}Th respectively in soil samples and the concentration-to-dose conversion factors are 0.042, 0.462 and 0.604, respectively.

Considering UNSCEAR, [23] report, which specified 0.2 as the outdoor occupancy factor (OF) and 0.70 Sv Gy^{-1} as the Dose Conversion Factor (DCF), the Annual Effective Dose Equivalent (AEDE) were obtained using the relation [24–26]

$$\mathrm{AEDE}\left(\mu\mathrm{Svy}^{-1}\right) = \mathrm{ADRA} \times \mathrm{DCF} \times \mathrm{OF} \times T \tag{7}$$

where T is 8760 h.

The excess lifetime cancer risks, which is the probability of an individual developing cancer over a lifetime when considering a specified exposure level was also calculated. The value obtained is the representation of the number of cancers that could be expected from a given number of people when exposed to a carcinogen at a given dose. The excess lifetime cancer risk (ELCR) was estimated using [27]

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

where AEDE is the annual effective dose equivalent, DL is the average duration of life and it was estimated to 45.5 years in Nigeria [28], and *RF* is the Risk Factor (Sv^{-1}). ICRP uses *RF* as 0.05 for the public [27].

Table 1
Activity concentration of radionuclides in soil.

State	Location	Soil type	Activity concentration (Bq kg^{-1})			
			^{40}K	^{226}Ra	^{232}Th	^{137}Cs
LAGOS	BADAGRY	SL	95.77	10.58	13.54	BDL
	OJOTA	L	235.49	22.67	40.09	BDL
	EPE	LC	76.87	31.18	46.33	1.27
	FESTAC	S	BDL	8.53	13.95	BDL
OGUN	ABEOKUTA	LC	533.28	58.05	194.23	1.37
	IJEBU-ODE	SC	43.27	64.95	47.31	0.89
	ILARO	L	23.96	29.01	28.72	BDL
OYO	IBADAN	L	330.11	61.13	101.37	BDL
	IGBOHO	L	1545.07	160.37	295.24	BDL
	OGBOMOSO	C	641.20	95.29	71.66	2.15
	OYO	S	305.05	26.79	23.98	BDL
OSUN	IKIRE	SL	462.44	59.34	99.78	BDL
	OSOGBO	S	374.33	65.07	48.88	BDL
	IFE	S	249.44	57.33	59.31	BDL
ONDO	AKURE	L	638.08	49.20	114.68	1.23
	OKITIPUPA	L	15.97	24.71	42.94	1.75
EKITI	ADO	L	886.86	46.58	67.68	BDL
	IKOLE	LC	236.28	81.62	72.50	BDL
	RANGE		BDL – 1545.07	8.53–160.37	13.54–295.24	BDL – 2.15
	MEAN		393.73	52.91	76.79	1.44

SL = Sandy loamy.
L = Loamy.
LC = Loamy clay.
S = Sandy.
SC = Sandy clay.
C = Clay.
BDL = Below detection limit.

Results and discussion

The activity concentrations of natural and artificial radionuclides, and soil-to-plant transfer factor were evaluated in soils and *Amaranthus hybridus* plants collected from different locations in the south-western Nigeria. The evaluation of radioactivity was performed in order to estimate the absorbed dose and cancer risk probability due to continuous exposure to ionizing radiation as a result of ingestion and inhalation of radionuclides from environmental matrices collected from the study area. The tables and graphical representations of the data are provided in the respective sections. Statistical analyses were performed using microcal origin software (version 6) to establish a relationship between different parameters measured and evaluated.

The results obtained in this study were compared across location of different activities and geology. The results were also analysed and compared with those from different literatures available, maximum permissible standards and the world average as appropriate.

A summary of the activity concentration of primordial radionuclides and artificial caesium in the soil and plant samples are presented in the Tables 1 and 2, respectively. The results of various measurements are presented and discussed in the following sections.

Activity concentration of natural radionuclides and artificial caesium in soil and plants

The activity concentration of ^{40}K is widely distributed across the study area. The highest activity concentration of natural radionuclides in soil was obtained from Igboho in Oyo State, this area is characterized by a rocky geology. The study revealed a non-uniform distribution of these radionuclides with activity concentration in the soil and plants varying significantly within a small area, which is due to the geological variability of the area.

The activity concentration of natural radionuclides in the study area was comparable with the world average value of 440 Bq kg^{-1} as reported by McAulay and Moran [29] and to 412 Bq kg^{-1} as reported by UNSCEAR [30].

The activity concentration of ^{137}Cs was low and varied within a narrow range. This radionuclide is of the fallout origin, and its concentration in a region depends largely on the local meteorological conditions, amount of rainfall, and the soil properties [31,32]. Large variations in the activity concentration of ^{137}Cs in a small region is not expected since its original fallout (due to weapon testing in the 1950s–60s and the Chernobyl accident) was influenced by the meteorological conditions, which does not vary within a small region. It is also known that there is no fresh input of ^{137}Cs to the environment.

Table 2
Activity concentration of radionuclides in plant (*Amaranthus hybridus*).

State	Location	Soil type	Activity concentration (Bq kg^{-1})			
			^{40}K	^{226}Ra	^{232}Th	^{137}Cs
LAGOS	BADAGRY	SL)	1353.38	20.64	19.50	BDL
	OJOTA	L	9221.05	40.24	1.77	BDL
	EPE	LC	4176.30	22.48	20.77	BDL
	FESTAC	S	2959.99	BDL	6.48	BDL
OGUN	ABEOKUTA	LC	2352.71	10.79	14.46	BDL
	IJEBU-ODE	SC	2235.26	30.58	25.79	BDL
	ILARO	L	2581.88	18.62	13.63	BDL
OYO	IBADAN	L	5773.51	33.62	14.82	BDL
	IGBOHO	L	681.90	45.33	34.43	BDL
	OGBOMOSO	C	2583.27	30.81	BDL	BDL
	OYO	S	3614.58	24.04	BDL	BDL
OSUN	IKIRE	SL	3667.24	15.80	9.46	BDL
	OSOGBO	S	2026.77	8.10	BDL	BDL
	IFE	S	1332.15	13.99	15.42	BDL
ONDO	AKURE	L	4619.88	22.52	19.24	BDL
	OKITIPUPA	L	1614.32	14.23	23.21	BDL
EKITI	ADO	L	3442.66	30.47	48.56	BDL
	IKOLE	LC	4652.95	57.73	30.94	BDL
	RANGE		681.90–9221.05	BDL – 57.73	BDL – 48.56	NA
	MEAN		3271.656	25.88176	19.89867	NA

SL = Sandy loamy.
L = Loamy.
LC = Loamy clay.
S = Sandy.
SC = Sandy clay.
C = Clay.
BDL = Below detection limit.

Transfer factors

The soil-to-plant transfer factors for the ^{40}K were found to be very high in majority of the study samples with a mean in the order of 26.58. The extremely high values of transfer factor for ^{40}K were observed in the cases where the concentration of ^{40}K in the soil samples was extremely low. This result is in agreement with the report of Karunakara et al. [33], who studied the soil-to-plant transfer factor for some wild forest plants of the Kaiga region and have shown that the ^{40}K transfer factor values were considerably higher for Kaiga region which may be due to the continuous accumulation of ^{40}K through the root uptake over a period of time. Al-Masri et al. [10] evaluated transfer factors values for ^{238}U, ^{210}Pb, ^{210}Po, and ^{40}K to various agricultural products (vegetables and fruit species) sampled from the districts of south Syria. Their studies revealed that ^{238}U, ^{210}Po, and ^{210}Pb transfer factors are higher in the leaves than the fruits, while ^{40}K transfer factors to the leaves and fruits were similar. In the present study ^{40}K transfer factors were found to be an order of magnitude higher when compared to the reported values. This higher uptake of ^{40}K may be due to the essential nutrient property of potassium to the plant.

The transfer factors for ^{226}Ra are higher than the soil-to-plant transfer factors reported by Uchida et al. [34] which varied in the range of 9.6×10^{-5}–8.6×10^{-3}. The soil-to-plant transfer factors for ^{232}Th varied in the range of 0.04–1.44 with a mean of 0.39. The transfer factors for ^{232}Th were close to those obtained for ^{226}Ra in this study. This result is in agreement with the fact that ^{232}Th/^{226}Ra ratio which must be close but greater than unity in any environmental matrix [35].

The soil-to-plant transfer factors for ^{137}Cs is not significant because of its low concentration in environmental samples as was obtained in this study. The result of this study showed that ^{137}Cs was not detected in any of the plant samples, and transfer factor is not applicable.

Dependence of transfer factors on the activity concentrations of radionuclides in soil

Linear uptake of elements by the plants was assumed in the estimation of transfer factors. This implies that the transfer factor for an element is constant under comparable conditions, irrespective of the element concentration in the soil [36]. Regression analyses were performed between activity concentrations of radionuclides in the soil and plant. The analyses as presented in Figs. 1–3 did not show a linear relationship between the transfer factor and activity concentration in soil for the primordial radionuclides. There were cases where activity concentrations in plants were relatively constant or with narrower variation range at widely varying soil concentrations. This resulted in a large random variation between the two parameters. Tuovinen et al. [36] made similar observations in their study on two forest sites in Eastern Finland.

Figs. 1–3 show that the soil-to-plant transfer factor for ^{40}K decreased with an increase in its activity concentration in the soil with a significant negative correlation coefficient (Fig. 1, $r = -0.524$). This indicates that the transfer factor value

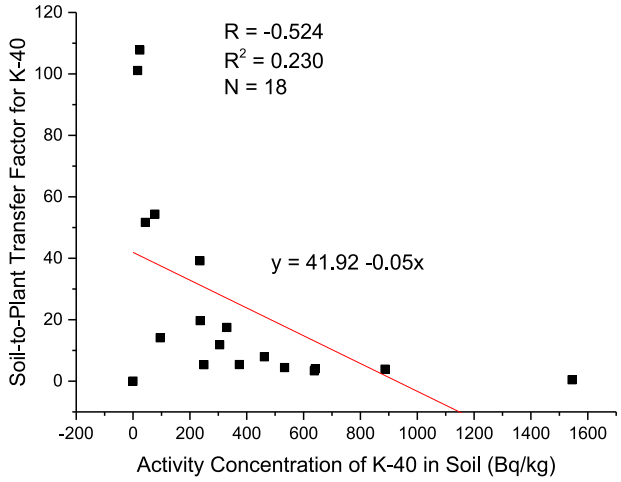

Fig 1. Soil-to-plant transfer factor negatively correlated with activity concentration of ^{40}K in soil.

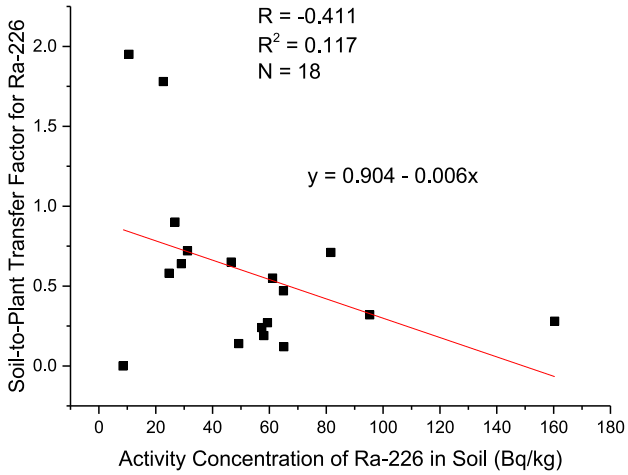

Fig 2. Soil-to-plant transfer factor negatively correlated with activity concentration of ^{226}Ra in soil.

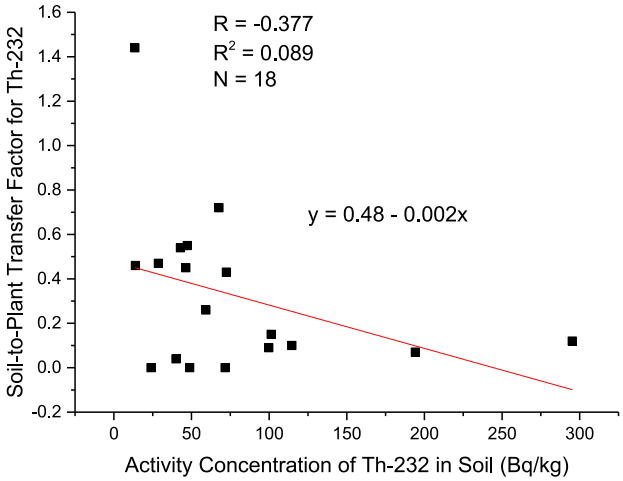

Fig 3. Soil-to-plant transfer factor negatively correlated with activity concentration of ^{232}Th in soil.

decreased with increasing soil activity concentration. Similar results were obtained for ^{226}Ra and ^{232}Th as presented in Figs. 2 and 3 respectively, which implies that the correlation coefficients between soil activity concentrations and the transfer factors have significant negative values with $r = -0.411$ and -0.377 respectively.

Results show that the soil-to-plant transfer factors were higher at low soil concentrations, and decreased with an increasing soil concentration. Tuovinen et al. [36], has reported that there is an evidence of non-linearity in the transfer of elements, both stable and radioactive, from soil to plants. He then argued that the soil-to-plant transfer factor is better described by a non-linear fit than the conventional constant transfer factor for both**,** essential and non-essential elements. McGee et al. [37] reported that the transfer of ^{137}Cs to native forest species in Ireland and Sweden did not follow the linear assumption. There are various literatures that reported that the assumption of constant transfer factors underestimates the transfer of U to native plant species at unmined ore bodies in various places like Canada and in some areas that are close to a fertiliser complex in Spain ([38,39]**;** and Martinez-Aquiree et al. [40]).

In their own study of the uptake of ^{40}K and ^{137}Cs by the plant species of the Marshall Islands, Simon et al. [41] observed a decreasing transfer factor with increasing soil concentrations. The reports from other studies have also shown that the transfer factor for various natural radionuclides were not constant over a wide range of soil concentrations [42–46].

The same trend was obtained in this study. There is a non-linear relationship between the activity concentrations of radionuclides in the soil and plant. This may be because the uptake of an element by the plants can be influenced by various factors. It has been observed that soil moisture can affect the availability of some element in the soils. Also, the cation exchange capacity, pH value, the organic matter content, nutrients in the soil and clay content, can seriously affect the availability of some element in the soils [41]. Considering the highlighted properties and their influence on radionuclide uptake and retention, the radionuclides that are present in higher concentrations are more likely to be retained in the soil, leading to a non-linear transfer to the plant. Notwithstanding, it is possible to have a linear relationship between the activity concentration of radionuclides in soil and the corresponding transfer factor if the experiments were performed in a finely controlled laboratory where all the conditions are uniform except the radioactivity concentration in the soil.

Radium equivalent activity (Ra_{eq})

The soil samples from Igboho and Abeokuta showed radium equivalent activity above the recommended limit of 370 Bq kg^{-1} [5]. However, the overall mean value was below this recommended limit. The values of radium equivalent activity obtained in the present study are higher when compared to the values reported for some other countries, which were in the range of 164.7–199.1 Bq kg^{-1} for China [47], 19.3–413.3 Bq kg^{-1} for Yemen [48], and 29.57–71.85 Bq kg^{-1} for Egypt [49].

External and internal hazard indices (H_{ex} and H_{in})

The acceptable value of H_{ex} and H_{in} must be less than 1 [20]. However, for the soil samples collected from Igboho and Abeokuta, H_{ex} was greater than 1 which is an indication that in these locations, the activity concentrations of ^{40}K, ^{232}Th, and ^{226}Ra were higher than recommended value for environmental safety. The highest values of H_{ex} (1.89) and H_{in} (2.33) were recorded at Igboho in Oyo State and the activity concentrations of ^{232}Th, ^{226}Ra, and ^{40}K were also high at this location. The high values of the external and internal hazard indices observed is attributable to the higher concentrations of ^{232}Th, ^{226}Ra, and ^{40}K in the study area due to the rocky nature of its local geology and soil constituents (Table 3).

Gamma absorbed dose rates due to primordial radionuclides

The gamma absorbed dose rates in the air are higher than the worldwide average value of 54 nGy h^{-1} [30].

The annual outdoor effective dose equivalent

The result of outdoor annual effective dose equivalent is presented in the Table 4 (106.00 μSv y^{-1}). With the corresponding worldwide average value of 72.50 μSv y^{-1} [5], it can be observed that the mean annual outdoor effective dose equivalent for the study area is higher than world average and higher than 0.1 mSv y^{-1} maximum limit recommended by WHO [50] but lower than 1 mSv y^{-1} limit recommended by NCRP [51] and ICRP [52]. This indicates that there are higher risks of radiation induced cancer in some locations in the study area where there is higher effective dose than what was recommended for human radiological safety. This could be because of the prevalence of rocks and their associated constituents of quartz and feldspar in the formation of these locations coupled with high agricultural activity and the use of soil enhancement chemical fertilizers.

The excess lifetime cancer risk

It was observed that the samples having higher (ELCR) were collected from high rocky geology areas. Long-term exposure to radiation could have some risks of causing cancer. This implies that every individual has a risk of getting cancer at a time in his lifetime. Reports from the National Cancer Institute, 2009 about Surveillance, Epidemiology, and End Results (SEER),

Table 3
Soil-to-plant transfer factor (TF) of natural radionuclides and artificial ^{137}Cs for *Amaranthus hybridus* plants across the locations.

State	Location	Soil type	Transfer factor			
			^{40}K	^{226}Ra	^{232}Th	^{137}Cs
LAGOS	BADAGRY	S/L	14.13	1.95	1.44	NA
	OJOTA	L	39.16	1.78	0.04	NA
	EPE	L/C	54.33	0.72	0.45	NA
	FESTAC	S	NA	NA	0.46	NA
OGUN	ABEOKUTA	C/L	4.41	0.19	0.07	NA
	IJEBU-ODE	S/C	51.66	0.47	0.55	NA
	ILARO	L	107.76	0.64	0.47	NA
OYO	IBADAN	L	17.49	0.55	0.15	NA
	IGBOHO	L	0.44	0.28	0.12	NA
	OGBOMOSO	C	4.03	0.32	NA	NA
	OYO	S	11.85	0.90	NA	NA
OSUN	IKIRE	S/L	7.93	0.27	0.09	NA
	OSOGBO	S	5.41	0.12	NA	NA
	IFE	S	5.34	0.24	0.26	NA
ONDO	AKUNGBA	C	3.35	0.14	0.10	NA
	OKITIPUPA	L	101.08	0.58	0.54	NA
EKITI	ADO	L	3.88	0.65	0.72	NA
	IKOLE	C/L	19.69	0.71	0.43	NA
	RANGE		0.44–107.76	0.12–1.95	0.04–1.44	NA
	MEAN		26.58	0.62	0.39	NA

Table 4
Radium equivalent (Ra_{eq}), external (H_{ex}), internal (H_{in}) hazard index, absorbed dose rate in air and annual effective dose equivalent for soil from south-west.

State	Location	H_{ex}	H_{in}	Ra_{eq}(Bq kg^{-1})	Absorbed dose Rate (nGy h^{-1})	Annual effective dose equivalent (μSv y^{-1})	ELCR × 10^{-5}
LA	BADAGRY	0.10	0.13	37.30	17.08	21.00	7.35
	OJOTA	0.27	0.33	98.13	44.58	54.70	19.15
	EPE	0.28	0.36	103.34	45.61	55.90	19.57
	FESTAC	0.08	0.10	28.47	12.36	15.20	5.32
OG	ABEOKUTA	1.02	1.17	376.86	166.53	204.20	71.47
	IJEBU-ODE	0.37	0.54	135.92	60.39	74.10	25.94
	ILARO	0.19	0.27	71.92	31.75	38.90	13.62
OY	IBADAN	0.63	0.79	231.51	103.33	126.70	44.35
	IGBOHO	1.89	2.33	701.53	317.31	389.10	136.19
		0.67	0.93	247.13	114.23	140.10	49.04
	OGBOMOSO						
	OYO	0.23	0.30	84.56	39.67	48.70	17.05
OS	IKIRE	0.64	0.80	237.62	107.10	131.30	45.96
	OSOGBO	0.44	0.62	163.78	75.30	92.40	32.34
	IFE	0.44	0.59	161.34	72.78	89.30	31.26
OD	AKURE	0.71	0.84	262.31	118.79	145.70	51.00
	OKITIPUPA	0.24	0.30	87.33	38.02	46.60	16.31
EK	ADO	0.57	0.70	211.65	99.65	122.20	42.77
	IKOLE	0.55	0.77	203.48	91.42	112.10	39.24
	MEAN	0.52	0.66	191.34	86.44	106.00	37.10
	RANGE	0.08–1.89	0.10–2.33	28.47–701.53	12.36–317.31	15.20–389.10	7.35–136,19

a cancer statistics review, showed that American men have a 44% lifetime risk of cancer, while women have a 38% lifetime risk. The Department of Environmental Quality (DEQ) considers an additional 1 in 100,000 chances (1×10^{-5}) allowable. The mean (ELCR) factor assessed in this work (3.71×10^{-4}) is higher than the world's average of 2.9×10^{-4} [23], which implies that there is higher cancer risk in the area of study due to exposure to ionizing radiation from primordial radionuclides. Pakistan Institute of Medical Sciences (PIMS) Islamabad reported numerous cancer deaths cases from the Northern Pakistan. According to its report, the cancer death could be related to the higher radioactivity in the area [53]. The value reported (3.70×10^{-4}) is very close to the result obtained in this work. This implies that cancer risk could be highly significant in the study area.

Conclusion

Environmental radioactivity assessment and soil-to-plant transfer factor has been carried out for soils and plants from 18 locations in the south-western Nigeria to evaluate the radiological impact level across the area. The results show that high

natural radioactivity level in soils is associated with rocky geology, which is mainly of sedimentary origin [54]. The mean for ^{40}K in the study area compares favourably with the earth's crustal mean of 400 Bq kg^{-1} [5].

There is a close to even distribution of radionuclides in plants across the study area. Activity Concentration in plants samples did not follow the trend that was obtained in soil samples. This is because activity concentration in plant samples does not depend solely on soil radioactivity, there are other channels of contamination of plants [5]. The highest activity concentration in plant were observed in areas where there is likely to be over dependence of chemical-based fertilizer for agricultural purposes.

Transfer factor is very high for ^{40}K most especially in areas where soil activity is low. This shows that transfer factor is not a function of soil radioactivity. The soil-to-plant transfer factors were higher at a place of low soil concentrations. The transfer factor decreased with an increasing soil concentration. Non-linearity in the transfer of elements, both stable and radioactive, from soil-to-plants was significantly evident as was reported earlier by Tuovinen et al. [36]. This supports their arguments that a non-linear fit describes soil to plant transfer factor better than the conventional constant transfer factor for both, essential and non-essential elements. There is a higher probability of lifetime cancer risk in the specific areas with heavy rock geology in the study area.

Conflict of interest

The authors have nothing to disclose.

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