International Journal of Natural Sciences Research
2022 Vol. 10, No. 1, pp. 88-101.
ISSN(e): 2311-4746
ISSN(p): 2311-7435
DOI: 10.18488/63.v10i1.3158

EVALUATION OF RADIONUCLIDES TRANSFER FACTORS AND INGESTION DOSE FROM PLANTS AROUND MINING SITES IN ADAMAWA STATE NIGERIA

Samson Dauda Yusuf[1+]
Soja, Reuben Joseph[2]
Ibrahim Umar[3]

[1,3]*Department of Physics, Faculty of Natural and Applied Sciences, Nasarawa State University, Keffi, Nigeria.*
[1]*Email: samsonyusufu@yahoo.com*
[3]*Email: jamazara@gmail.com*
[2]*Nigerian Nuclear Regulatory Authority, Abuja Nigeria.*
[2]*Email: sojareuben@gmail.com*

(+ Corresponding author)

Article History
Received: 26 July 2022
Revised: 2 September 2022
Accepted: 19 September 2022
Published: 6 October 2022

Keywords
Activity concentration
IMBA
Ingestion dose
Internal dose
Natural radioactivity
Radiation exposure
Transfer factors.

ABSTRACT

Illegal mining activities has become rampant in Adamawa State Nigeria, contaminating the soil with radionuclides which can be transferred to the food crops farmed in the host communities. Ingestion of such plants could cause harmful effects. In this study, radionuclide transfer factor from soil to plants and internal exposure dose around mining sites in Adamawa State were evaluated. 30 (15 soil, 15 plant) samples were analyzed for activity concentrations of 226Ra, 232Th and 40K. The transfer factor from soil to plant was calculated and the ingestion dose was also calculated using the Integrated Module for Bioassay Analysis (IMBA). Result shows that the mean activity concentrations of 226Ra, 232Th and 40K in the soil are 106.32Bq/kg, 84.34Bq/kg and 466.14Bq/kg, while for plants are 98.42Bq/kg, 72.69Bq/kg and 274.07Bq/kg respectively. These values were above the world average by United Nations Scientific Community on the Effects of Atomic Radiation (UNSCEAR) 35Bq/kg, 30Bq/kg and 400Bq/kg except for 40K which was lower in plant samples. Mean transfer factors were 0.942, 0.919 and 1.149 respectively, corresponding to a mean ingestion dose of 1.02E-01mSv/y, indicating high transfer factor in all the mining sites and high ingestion doses. Even though the mean ingestion dose was low, ingestion of such plants may pose radiation risk to the host communities in a long time. Therefore, proper policy by regulatory authorities must be put in place to protect the host community and the public from high ingestion doses that accounts for internal radiation exposure especially mining sites A, B and C.

Contribution/Originality: The authors successfully evaluated the transfer factor of natural radioactivity from soil to plants using primary data of activity concentrations of Ra-226, Th-232 and K-40 from the study area. In addition, they also estimated ingestion dose from consumption of such plants using IMBA internal dosimetry code, which serve as a baseline for policy implementation.

1. INTRODUCTION

Naturally found radioactive elements are the primary causes of both direct and indirect human exposure to radiation and can be found in the air that we breathe, the food that we consume, as well as the drinking waters, triggering public health concerns [1]. Ionizing radiation exposure causes health concerns after a few years [2]. Radon and Thoron, which are disintegration products of ^{238}U and ^{232}Th widely found within rocks and soils, are the most significant contributors to exposure to radiation. The excessive exposure to such radionuclides may be detrimental to the public, since naturally radiation level contributes the most to human exposure [3].

Environmental exposures are primarily caused by ancestral radioactive elements, which are found in practically all sedimentary elements within ecological environment and are extensively distributed. Such radioactive materials are referred to as Naturally Occurring Radioactive Material (NORM) including ^{238}U and ^{232}Th, as well as the single decay ^{40}K radionuclides, makes up the vast bulk of NORMs. Such radionuclides reach the living organism through the food chain, mostly through consumption [4]. These radionuclides are taken up by plants via the origins and aggregate in various edible sections. The accumulating radioactive elements in such plants provide an internal radiation exposure to people when they are prepared and ingested [5].

Upon atmospheric discharge of radioactive particles, plants are the main consumers of radioactive fallout into the food chain. Roots absorption or abrupt airborne deposits of dispersed radioactive particles on crops are indeed the two most common ways for plants to become contaminated [6]. To identify the level of danger and adverse consequences on public health, a precise assessment of such radioactive particles in commonly consumed dietary products is required. In addition, a small amount of radioactivity in the soil is distributed to plants. Plants take radioactive elements from the soil and feeds them to humans. The transfer factor (TF) is a term that describes how plants absorb radioactive elements from the soil [7]. These trees absorb accumulated radioactive elements from the soil, which is identified as the soil-to-plant transfer factor and is used to calculate radiological human dosage through the ingesting route. Among the most important metrics in measuring the level of radioactive fallout in plants and its consequences of adding to internal dosage is the soil-to-plant TF [8]. Soil texture, permittivity, pH, physical facilities ratio, transportable K+, soil structure, or alkalinity concentration all affect radioactivity passage from soil to plants [9].

The ratio of the concentration level (in Bqkg-1) in dry mass of the plants to the concentration level (in Bqkg-1) in dry weight of the soil is known as the soil-to-plant Transfer factor [10]. The TF indicator is often used to evaluate the influence of daily and inadvertent radioactive releases into the surroundings and the risk of contamination of plants. Both physical and chemical characteristics of radioactive elements in the soil, the kind of plants, soil composition, fertilizer, and climatic conditions, all influence soil-to-plant transfer factors. The absorbed dose is the amount of energy transmitted by radioactive substances to the weight or volume. The likelihood of damaging human health is proportional to the dose received [11]. Exposure pathway of radionuclides to humans can be as a result of either ingestion through eating, inhalation through radio-particle dust contaminated air or absorption/contamination through the skin. The objective of this paper is to evaluate the radionuclide TF from soil to plants obtained around some mining sites in Adamawa State and to estimate the internal dose resulting from ingestion of contaminated plants obtained from the study area. Numerous research on the subject have been conducted in various regions. Nevertheless, there seems to be limited research evaluation of transfer factors and radionuclide ingestion dose resulting from consumption of plants around the chosen areas, considering the facts that; a lot of mining activities have been going on for a long period of time which may give rise to radiation exposure in the area.

2. METHODOLOGY

2.1. Study Area

Adamawa State is located in the north-eastern section of Nigeria, with a land mass of 39,742.12 square kilometres, accounting for around 4.4 percent of Nigeria's total land mass. It is located between latitudes 80 and 110 degrees north, and longitudes 11.50 and 13.50 degrees east. The state essentially has a picturesque mountainous land traversed by big river valley of Benue, Gongola and Yadzaram with abundance of solid minerals.

2.2. Integrated Module for Bioassay Analysis (IMBA) Code

Public Health England created the Integrated Module for Bioassay Analysis (IMBA) software to assess the internal doses, which can result from radioactive intakes or bioassay data acquisition in various circumstances. The

program utilizes the ICRP [12] dose coefficient and some other variables from publications 26, 30, 56, 66, 67, 68, and 69, as well as the National Council on Radiation Protection (NCRP) 156. It also employs the Guidelines of Federal Regulations for different technical dose measurements resulting from various exposure pathways including inhalation, ingestion, injection, wound, and gaseous routes by employing the bio-kinetic and dosimetry models in bioassay and dose assessments accordingly [13].

2.3. Methods

2.3.1. Sampling Technique

Using systematic sampling techniques, thirty (30) samples comprising of fifteen (15) soil and fifteen (15) plant samples each were gathered from four (4) quarry-mining sites located 500 meters apart. To avoid cross contamination during transit, composite samples were collected using a shovel at a depth of about 10cm and placed in a sealed labelled polythene bag. To eliminate moisture, open air-drying at room temperature for seven days was used, and stone samples were ground into powdery form with a mortar and pestle and sieved with a wire mesh with holes of thickness 0.5mm to achieve uniformity of sample size. Composite plant samples were obtained from the same location of the corresponding soil sampling points for accurate assessment of transfer factors. The sample locations for the quarry mining sites along with their respective coordinates and sampling codes are presented in Table 1.

Table 1. Sampling locations, codes and coordinates.

Mining Locations	Soil Sample Code	Plant Sample Code	Sampling Coordinates	
			Latitude	Longitude
Raycon Fufore	S - A1	P - A1	09^0 08' 36"	12^0 19' 09"
Raycon Fufore	S - A2	P - A2	09^0 08' 29"	12^0 19' 19"
Raycon Fufore	S - A3	P - A3	09^0 08' 23"	12^0 19' 04"
Raycon Fufore	S - A4	P - A4	09^0 08' 39"	12^0 19' 14"
NRC Demsa	S - B1	P - B1	09^0 21' 48"	12^0 11' 32"
NRC Demsa	S - B2	P - B2	09^0 21' 42"	12^0 11' 28"
NRC Demsa	S - B3	P - B3	09^0 21' 36"	12^0 11' 22"
NRC Demsa	S - B4	P - B4	09^0 21' 53"	12^0 11' 19"
Ministry Demsa	S - C1	P - C1	09^0 21' 55"	12^0 11' 23"
Ministry Demsa	S - C2	P - C2	09^0 21' 51"	12^0 11' 20"
Ministry Demsa	S - C3	P - C3	09^0 21' 45"	12^0 11' 17"
Ministry Demsa	S - C4	P - C4	09^0 21' 59"	12^0 11' 13"
AG Vision Song	S - D1	P - D1	09^0 56' 15"	12^0 37' 46"
AG Vision Song	S - D2	P - D2	09^0 56' 19"	12^0 37' 39"
AG Vision Song	S - D3	P - D3	09^0 56' 11"	12^0 37' 44"

Note: NRC is Nigeria Road Construction Company Limited, AG is Abou Ghazaleh Construction Company.

2.3.2. Measurement of Activity Concentration (AC)

The samples were analysed to determine the radioactivity concentration levels of ^{226}Ra, ^{232}Th, and ^{40}K in soil and plants using Gamma ray spectroscopy with a well calibrated sodium iodide NaI (Tl) detector at the Centre for Energy Research and Training (CERT) Laboratory, Ahmadu Bello University Zaria, Nigeria.

2.3.3. Measurement of Transfer Factors from Soil to Plants

Transfer Factors (TF) form soil to plants were analyzed using the equation as expressed by [11] as:

$$TF = \frac{Activity\ Concentration\ of\ radionuclide\ in\ dry\ weight\ of\ plant\ \left(Bq/kg\right)}{Activity\ Concentration\ of\ radionuclide\ in\ dry\ weight\ of\ soil\ \left(Bq/kg\right)} \quad (1)$$

2.3.4. Measurement of Ingestion Dose

The Ingestion dose resulting from ingestion of contaminated plants were calculated using Integrated Module for Bioassay Analysis (IMBA) computer code using the measured activity concentration of ^{226}Ra, ^{232}Th and ^{40}K (Bq/kg) in plant samples obtained from the four mining sites, duration of ingestions based on the average life span, Standard ICRP [12] Ingestion rate (hr/yr), Inadvertent Ingestion rate (kg/hr), and Ingestion dose conversion factors (Sv/Bq).

3. RESULTS

3.1. Activity Concentration

Table 2 and Table 3 shows the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil and plant samples respectively obtained from four selected mining sites in Adamawa State while Figure 1 and Figure 2 shows their corresponding mean activity concentrations.

Table 2. Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples.

Soil Sample Code	Ra-226 (Bq/Kg)	Th-232 (Bq/Kg)	K-40 (Bq/Kg)
S - A1	88.29	78.72	1080.28
S - A2	120.29	92.67	1074.70
S - A3	104.59	92.79	941.28
S - A4	121.72	76.67	342.61
Mean (S-A)	108.72	85.21	859.72
S - B1	99.83	73.02	368.83
S - B2	114.29	157.24	251.34
S - B3	95.92	76.59	441.98
S - B4	144.97	81.31	527.35
Mean (S-B)	113.75	97.04	397.38
S - C1	104.91	110.64	295.05
S - C2	124.40	92.40	352.96
S - C3	110.38	52.92	261.69
S - C4	122.64	60.00	208.01
Mean (S-C)	115.58	78.99	279.43
S - D1	89.37	82.49	174.07
S - D2	75.54	64.09	45.67
S - D3	96.80	81.74	764.32
Mean (S-D)	87.24	76.11	328.02
Overall Mean	106.32	84.34	466.14
UNSCEAR [14] Standard	35.00	30.00	400.00
Con. Ratio	3.038	2.811	1.165

From Table 2, the order of mean activity concentration (AC) value of ^{226}Ra in soil samples from the four selected mining sites is S-C (115.58Bq/kg) > S-B (113.75Bq/kg) > S-A (108.72Bq/kg) > S-D (87.27Bq/kg), with an overall mean value 106.32Bq/kg for the four (4) mining sites. These mean values from the individual mining sites and the overall mean were all above the world average value of 35Bq/kg according to UNSCEAR [11].

The order of mean AC value of ^{232}Th in soil samples from the four mining sites is S-B (97.04Bq/kg) > S-A (85.21Bq/kg) > S-C (78.99Bq/kg) > S-D (76.11Bq/kg), with an overall mean value 84.34Bq/kg for the four (4) mining sites. These mean values from the individual mining sites and the overall mean were all above the world average value of 30Bq/kg according to UNSCEAR [11].

The order of mean AC value of ^{40}K in soil samples amongst the individual mining sites is S-A (859.72Bq/kg) > S-B (397.38Bq/kg) > S-D (328.02Bq/kg) > S-C (279.43Bq/kg). The mean AC value of ^{40}K from mining site S-A was above the recommended world average value, while the mean values from mining S-B, S-C, and S-D were all below the world average value 400Bq/kg according to UNSCEAR [11]. Consequently, the overall mean AC value

of ^{40}K in soil samples was 466.14Bq/kg for the four (4) mining sites which is above the recommended world average value.

The AC values of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples varies across each mining sites with their overall mean values 106.32Bq/kg, 84.34Bq/kg and 466.14Bq/kg respectively which are all above the recommended world average values 35Bq/kg, 30Bq/kg and 400Bq/kg according to UNSCEAR [11]. The order of their concentration in the soil samples were: ^{226}Ra > ^{232}Th > ^{40}K as indicated by their concentration ratio. However, even though ^{40}K has the highest overall mean AC in the soil samples, findings from this study have shown that the host community are more open to ^{226}Ra and ^{232}Th as against ^{40}K, except for mining site S-A (Raycon mining) where the AC value was high. The mean AC for ^{226}Ra, ^{232}Th and ^{40}K in soil samples for the individual mining sites and the overall mean AC values is shown in Figure 1.

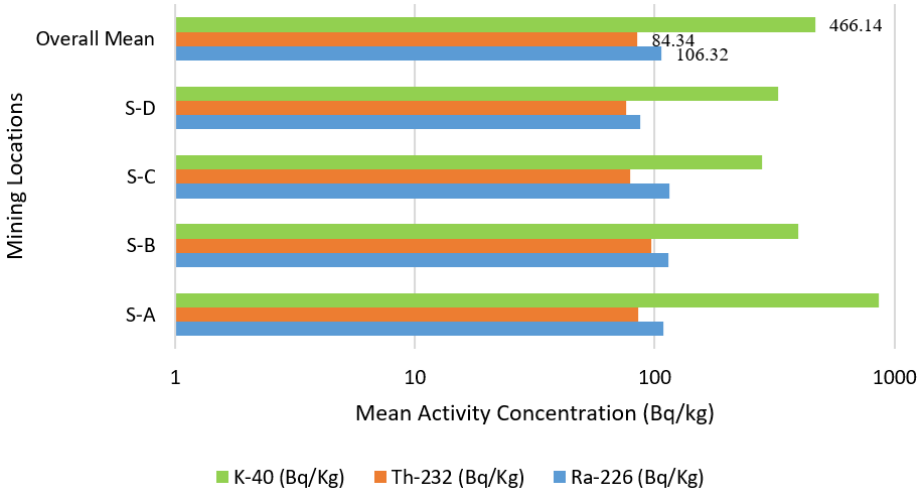

Figure 1. Mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples.

Table 3. Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in plant samples.

Plant Sample Code	Ra-226 (Bq/Kg)	Th-232 (Bq/Kg)	K-40 (Bq/Kg)
P-A1	91.92	68.30	236.92
P-A2	79.70	76.75	223.67
P-A3	114.09	69.47	204.85
P-A4	96.88	89.14	217.72
Mean (P-A)	95.65	75.92	220.79
P-B1	84.57	92.20	246.25
P-B2	121.72	93.58	253.27
P-B3	91.88	54.18	139.00
P-B4	92.60	68.38	231.66
Mean (P-B)	97.69	77.09	217.55
P-C1	139.54	54.06	316.23
P-C2	116.97	84.26	150.58
P-C3	79.62	96.96	524.72
P-C4	107.94	58.15	264.43
Mean (P-C)	111.02	73.36	313.99
P-D1	91.32	57.68	285.55
P-D2	79.50	77.38	233.32
P-D3	97.11	58.11	512.98
Mean (P-D)	89.31	64.39	343.95
Overall Mean	98.42	72.69	274.07
UNSCEAR [14] Standard	35.00	30.00	400.00
Con. Ratio	2.812	2.423	0.685

From Table 3, the order of mean AC value of ^{226}Ra in plant samples from the four selected mining sites is P-C (111.02Bq/kg) > P-B (97.67Bq/kg) > P-A (95.65Bq/kg) > P-D (89.31Bq/kg), with an overall mean value 98.42Bq/kg for the four (4) mining sites. These mean values from the individual mining sites and the overall mean were all above the world average value of 35Bq/kg according to [11].

The order of mean AC value of ^{232}Th in plant samples from the four mining sites is P-B (77.09Bq/kg) > P-A (75.92Bq/kg) > P-C (73.36Bq/kg) > P-D (64.39Bq/kg), with an overall mean value 72.69Bq/kg for the four (4) mining sites. These mean values from the individual mining sites and the overall mean were all above the world average value of 30Bq/kg according to UNSCEAR [11].

The order of mean AC value of ^{40}K in plant samples amongst the individual mining sites is P-D (343.95Bq/kg) > P-C (313.99Bq/kg) > P-A (220.79Bq/kg) > P-B (217.55Bq/kg), with an overall mean value 274.07Bq/kg for the four (4) mining sites. These mean values from the individual mining sites and the overall mean were all below the world average value of 400Bq/kg according to UNSCEAR [11].

The AC values of ^{226}Ra, ^{232}Th, and ^{40}K in plant samples varies across each mining sites with the overall mean values 98.42Bq/kg, 72.69Bq/kg and 274.07Bq/kg respectively. The mean values of ^{226}Ra and ^{232}Th were above the world average values 35Bq/kg and 30Bq/kg, while that of ^{40}K was below the world average value 400Bq/kg as according to UNSCEAR [11]. The order of activity concentration in the plant samples were: ^{226}Ra > ^{232}Th > ^{40}K. However, even though ^{40}K has the highest overall mean AC in the plant samples, findings from this study have shown that the host community are more open to ^{226}Ra and ^{232}Th as against ^{40}K as indicated by their concentration ratio. Therefore, ^{226}Ra and ^{232}Th presents in soil samples have the tendency of been metabolically absorbed into the plants resulting in hazard to the consumers in the long run. The mean AC values for ^{226}Ra, ^{232}Th and ^{40}K in plant samples for the individual mining sites and the overall mean AC is shown in Figure 2.

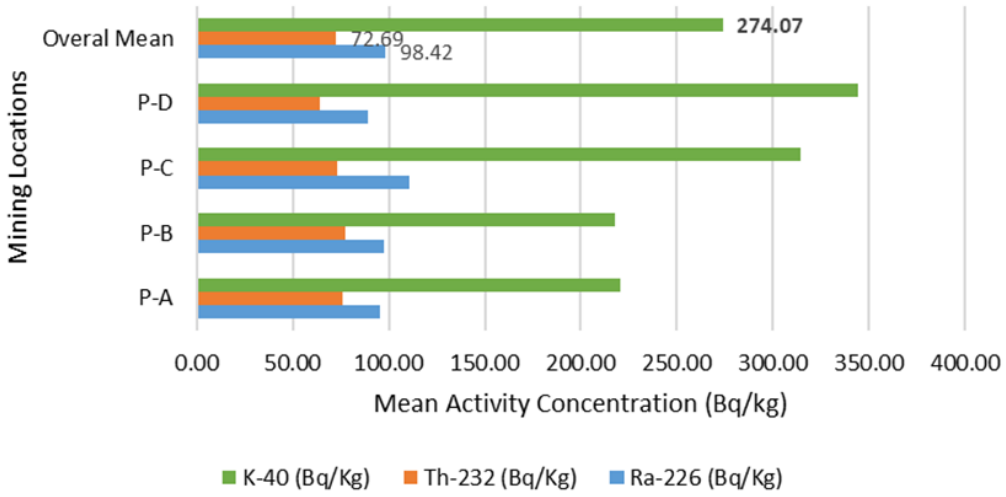

Figure 2. Mean Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in plant samples.

3.2. Evaluation of Transfer Factors

Soil to plants TF were evaluated using the determined activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil and plants samples using Equation 1 and the results are presented in Table 4.

From Table 4, the order of mean transfer factor (TF) value of ^{226}Ra from soil to plant from the four selected mining sites is P-D (1.0258) > P-C (0.9680) > P-A (0.8976) > P-B (0.8772), with an overall mean value 0.942 for the four (4) mining sites. These indicates low TF of ^{226}Ra from the individual mining sites except at mining site P-D where the transfer factor is high. However, the overall TF value of ^{226}Ra is low.

The order of mean TF value of ^{232}Th from soil to plant from the four mining sites is P-C (1.0505) > P-A (0.9018) > P-D (0.8725) > P-B (0.8515), with an overall mean value 0.919 for the four (4) mining sites. These

indicates low TF of ^{232}Th from the individual mining sites except at mining site P-C where the transfer factor is high. Again, the overall TF value of ^{232}Th is low.

The order of mean TF value of ^{40}K from soil to plant amongst the individual mining sites is P-D (2.4735) > P-C (1.1937) > P-B (0.6073) > P-A (0.3201), with an overall mean value 1.149 for the four (4) mining sites. These indicates high TF of ^{40}K from the individual mining sites except for mining sites P-B and P-A where the transfer factors are low. The overall TF value of ^{40}K in this case is very high.

Table 4. Radionuclides transfer factor (TF) from soil to plant.

Soil Sample ID	Plant Sample ID	Transfer Factors		
		^{226}Ra	^{232}Th	^{40}K
S - A1	P - A1	1.041	0.868	0.219
S - A2	P - A2	0.663	0.828	0.208
S - A3	P - A3	1.091	0.749	0.218
S - A4	P - A4	0.796	1.163	0.636
S-A	P-A	0.898	0.902	0.320
S - B1	P - B1	0.847	1.263	0.668
S - B2	P - B2	1.065	0.595	1.008
S - B3	P - B3	0.958	0.707	0.315
S - B4	P - B4	0.639	0.841	0.439
S-B	P-B	0.877	0.852	0.607
S - C1	P - C1	1.330	0.489	1.072
S - C2	P - C2	0.941	0.912	0.427
S - C3	P - C3	0.722	1.832	2.005
S - C4	P - C4	0.880	0.969	1.271
S-C	P-C	0.968	1.051	1.194
S - D1	P - D1	1.022	0.699	1.640
S - D2	P - D2	1.052	1.207	5.109
S - D3	P - D3	1.003	0.711	0.671
S-D	P-D	1.026	0.873	2.474
Overall Mean		0.942	0.919	1.149

The TF values of ^{226}Ra, ^{232}Th, and ^{40}K from soil to plant varies across each mining sites with the overall mean values 0.942, 0.919 and 1.149 respectively. These indicates low TF of ^{226}Ra and ^{232}Th, while high TF of ^{40}K. The order of TF from soil to plant were: ^{40}K > ^{226}Ra > ^{232}Th. However, high TF of ^{232}Th and ^{40}K were associated with mining site P-C, while high TF of ^{226}Ra and ^{40}K were associated with mining site P-D. The mean transfer factor value from soil to plants is shown in Figure 3.

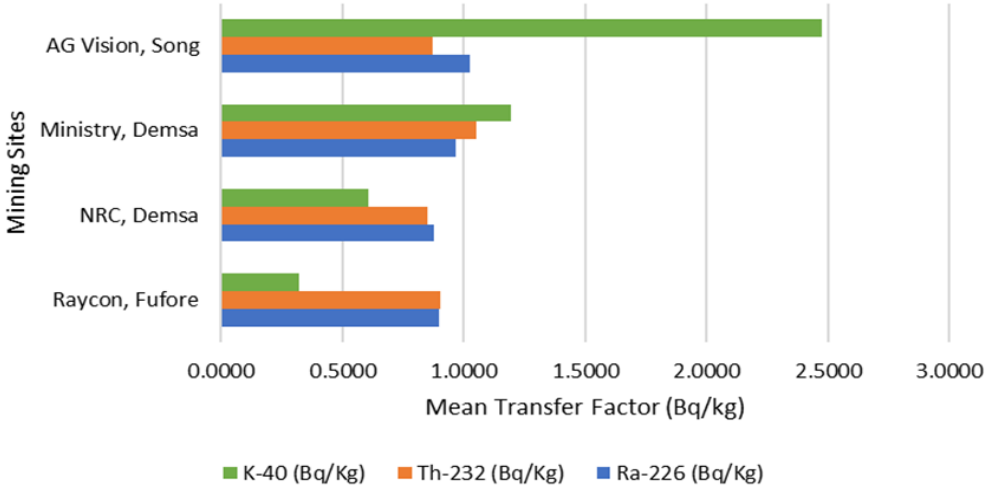

Figure 3. Mean transfer factor value from soil to plants (Bq/kg).

3.3. Estimation of Ingestion Dose

3.3.1. Estimation of Ingestion Dose from Individual Radionuclides

Ingestion dose were estimated using IMBA code from the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in plants samples and the result are presented in Table 5.

Table 5. Ingestion dose of ^{226}Ra, ^{232}Th and ^{40}K in plants samples.

Plant Sample Code	Mean Sample Per Location	Ra-226 Ingestion dose (mSv/y)	Ra-226 Mean dose (mSv/y) Per Location	Th-232 Ingestion dose (mSv/y)	Th-232 Mean dose (mSv/y) Per Location	K-40 Ingestion dose (mSv/yr)	K-40 Mean dose (mSv/y) Per Location
P-A1	PA	2.08E-02	2.16E-02	8.09E-02	9.00E-02	6.70E-04	6.24E-04
P-A2		1.80E-02		9.09E-02		6.32E-04	
P-A3		2.58E-02		8.23E-02		5.79E-04	
P-A4		2.19E-02		1.06E-01		6.16E-04	
P-B1	PB	1.91E-02	2.21E-02	1.09E-01	9.13E-02	6.96E-04	6.15E-04
P-B2		2.75E-02		1.11E-01		7.16E-04	
P-B3		2.07E-02		6.42E-02		3.93E-04	
P-B4		2.09E-02		8.10E-02		6.55E-04	
P-C1	PC	3.15E-02	2.51E-02	6.40E-02	7.58E-02	8.94E-04	8.87E-04
P-C2		2.64E-02		9.98E-02		4.26E-04	
P-C3		1.80E-02		1.15E-01		1.48E-03	
P-C4		2.44E-02		2.44E-02		7.48E-04	
P-D1	PD	2.06E-02	2.02E-02	6.78E-02	7.61E-02	8.07E-04	9.72E-04
P-D2		1.80E-02		9.17E-02		6.60E-04	
P-D3		2.19E-02		6.88E-02		1.45E-03	
Mean			2.23E-02		8.33E-02		7.75E-04

From Table 5, the order of mean ingestion dose (ID) value of ^{226}Ra in plant samples from the four selected mining sites is P-C (2.51E-02mSv/y) > P-B (2.21E-02mSv/y) > P-A (2.16E-02mSv/y) > P-D (2.02E-02mSv/y), with an overall mean value 2.23E-02mSv/y for the four (4) mining sites. These indicates low ID of ^{226}Ra from the individual mining sites. The overall ID value of ^{226}Ra is low.

The order of mean ID value of ^{232}Th in plant samples from the four mining sites is P-B (9.13E-02mSv/y) > P-A (9.00E-02mSv/y) > P-D (7.61E-02mSv/y) > P-C (0.8515mSv/y), with an overall mean value 8.33E-02mSv/y for the four (4) mining sites. These indicates low ID of ^{232}Th from the individual mining sites. Again, the overall ID value of ^{232}Th is low.

The order of mean ID value of ^{40}K in plant samples amongst the individual mining sites is P-D (9.72E-04mSv/y) > P-C (8.87E-04mSv/y) > P-A (6.24E-04mSv/y) > P-B (6.15E-04mSv/y), with an overall mean value 7.75E-04mSv/y for the four (4) mining sites. These indicates low ID of ^{40}K from the individual mining sites. The overall ID value of ^{40}K is also low. This is because the concentration of ^{40}K in the body is homeostatically controlled and is therefore independent of the intake because it scales with the intake of stable potassium, which implies that; the specific activity of ^{40}K in the body is equal to the specific activity of the ^{40}K ingested.

The ID values of ^{226}Ra, ^{232}Th, and ^{40}K in plants varies across each mining sites with the overall mean values 2.23E-02mSv/y, 8.33E-02mSv/y and 7.75E-04mSv/y respectively. These indicates low ID values. The order of ID in the plant samples were: ^{232}Th > ^{226}Ra > ^{40}K >. The mean ingestion dose of ^{226}Ra, ^{232}Th and ^{40}K in plant samples is shown in Figure 4.

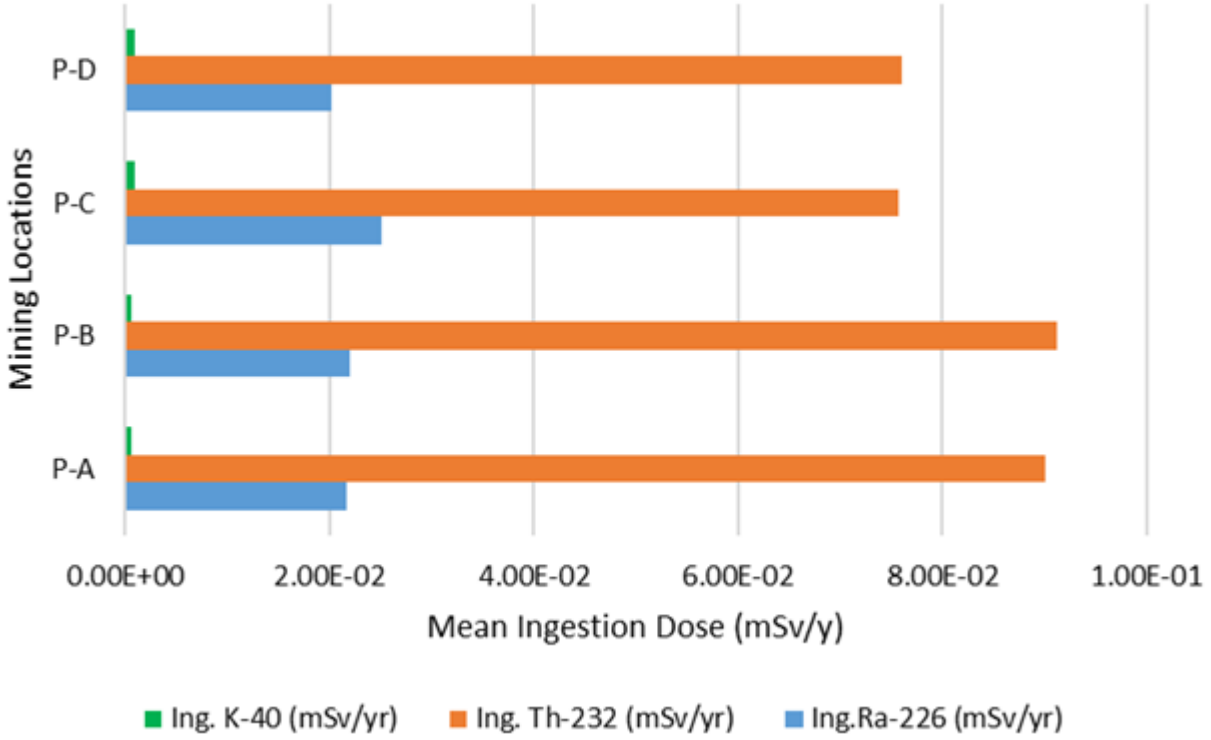

Figure 4. Mean ingestion dose of ^{226}Ra, ^{232}Th and ^{40}K in plants samples.

3.3.2. Estimation of Total Ingestion Dose

Total Ingestion dose (mSv/y) from ingestion of contaminated plants around mining site were calculated using the summation of ingestion dose calculated from activity concentration level of ^{226}Ra, ^{232}Th and ^{40}K in plants samples and the results is presented in Table 6.

Table 6. Total ingestion dose (mSv/y).

Mining Locations	Plant Sample Code	Mean Plant Sample ID	Total Ingestion Dose (mSv/y)	Total Mean Ingestion dose per site (mSv/y)
Raycon, Fufore	P-A1	P-A	1.02E-01	1.12E-01
	P-A2		1.10E-01	
	P-A3		1.09E-01	
	P-A4		1.29E-01	
NRC, Demsa	P-B1	P-B	1.29E-01	1.14E-01
	P-B2		1.39E-01	
	P-B3		8.53E-02	
	P-B4		1.03E-01	
Ministry, Demsa	P-C1	P-C	9.64E-02	1.02E-01
	P-C2		1.27E-01	
	P-C3		1.34E-01	
	P-C4		4.95E-02	
AG Vision, Song	P-D1	P-D	8.92E-02	7.29E-02
	P-D2		1.10E-01	
	P-D3		9.22E-02	
Total Mean				1.002E-01

From Table 6, the total ingestion dose (TID) value in plant samples amongst the individual mining sites varies from mining site to mining site. The order is P-B (1.14E-01mSv/y) > P-A (1.12E-01mSv/y> P-C (1.02E-01mSv/y) > P-D (0.729E-01mSv/y) with mean total dose 1.002E-01mSv/y. The TID value in plant samples falls below the world average value of 0.3mSv/y according to UNSCEAR [11]. Though, the result from this study only accounted for contribution from ingestion pathway resulting from consumption of contaminated crops around mining sites.

However, even at low dose, modern ICRP [12] recommendations are founded on the assumption that "no safe level of radiation exposure" since the low radiation dose has the tendency of resulting to stochastic consequences in the long run. The total mean ingestion dose from each mining site is presented in Figure 5.

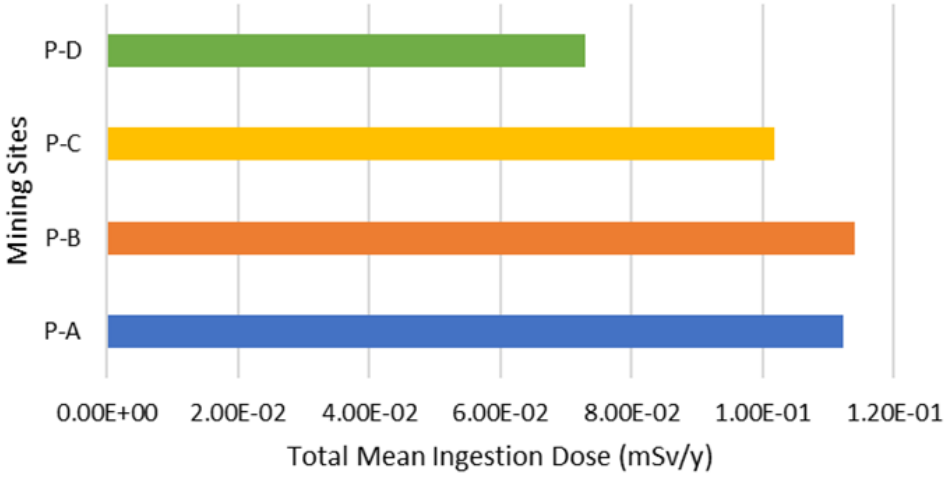

Figure 5. Total ingestion dose from each mining locations.

4. DISCUSSION

Previous research shows that the amount of minerals and the unique geology for every location, natural radioactivity differs from one place to another, with larger departures from baseline limits. The existence of naturally occurring radionuclides in the surroundings can result in a person being exposed to doses of radiation by direct or indirect means through ingestion and inhalation [15]. Findings have shown that radionuclide AC in soil and plants varied within the study area due to the geological and topographical differences. The mean AC values of ^{226}Ra, ^{232}Th and ^{40}K in soil obtained from the study areas are 106.32Bq/kg, 84.34Bq/kg and 466.14Bq/kg respectively. These values were all above the world average values 35Bq/kg, 30Bq/kg and 400Bq/kg respectively according to UNSCEAR [11]. These findings are in line with Shittu, et al. [16] in Abuja, Jibiri, et al. [17] in Jos, Plateau State and Ibrahim, et al. [14] in Nasarawa State. However, these mean values were higher than those obtained by Samuel, et al. [6] (12.14Bq/kg, 23.23Bq/kg and 270.14Bq/kg) in Osun, Nigeria. The mean AC values of ^{226}Ra and ^{40}K in the present study were higher than those obtained in Anka, Nigeria by Mbet, et al. [18] (41.6Bq/kg and 380.34Bq/kg) and Ibikunle, et al. [8] (52.91Bq/kg and 393.73Bq/kg) in some selected cities in South Western Nigeria. The mean concentration of ^{226}Ra in the present study was significantly lower than that reported in Gabon by Mouandza, et al. [19] (2811 Bq/kg), also for ^{232}Th, the present value was less than that of Mbet, et al. [18] (151.15Bq/kg) in Anka, and for ^{40}K, the present study reported less concentration than Okeme, et al. [5] (639.52Bq/kg) in Kogi State, Nigeria.

Findings from this study have revealed that the AC in plants samples varied within the study area due to the difference in radionuclide concentrations in soil, the absorption rate of plants and the geological formation of the study area. The mean AC values of ^{226}Ra and ^{232}Th (98.42Bq/kg and 72.69Bq/kg) in plants were higher than world average values 35Bq/kg and 30Bq/kg while that of ^{40}K (274.07Bq/kg) in plants was less than world average value 400Bq/kg as according to UNSCEAR [11]. The mean concentrations in plants for this study were higher than those reported by Adeleke, et al. [20] (4.7Bq/kg, 8.5Bq/kg and 88.67Bq/kg) from medicinal plants in Minna and Kaduna State, Nigeria. Also, the mean concentrations were higher than those reported in Kogi State, Nigeria by Okeme, et al. [5] (12.73Bq/kg, 10.36Bq/kg and 41.15Bq/kg). The values were higher than those reported by Oluyide, et al. [21] (56Bq/kg, 13.17Bq/kg and 89.41Bq/kg) in Osun State, Nigeria for ^{226}Ra, ^{232}Th and ^{40}K respectively.

Previous studies have indicated that TF is a measure of the level of the radionuclides in the plant as a fraction of the soils total [22] and their uptake by plants differs from one radionuclide to another, from one plant species to another and from one dumpsite/mining site to the other [23, 24]. However, TF values greater than one (TF >1) implies effective transfer of radionuclides from the root to the aerial parts, and from the shoot to the leaf and the fruit [25]. Findings from the present study have revealed that the mean TF values for ^{226}Ra, ^{232}Th and ^{40}K (0.942, 0.919 and 1.149) were higher than those reported in Ogun, Nigeria by Alausa, et al. [26] (0.23, 0.20 and 0.38). The mean TF values for ^{226}Ra, and ^{232}Th in the present study were also higher than those reported by Gaffar, et al. [27] (0.39 and 0.40) in Malaysia, Ibikunle, et al. [8] (0.31 and 0.62) in south western Nigeria, Mohannad and Khalil [9] (0.60 and 0.31) in Palestine, and Harb, et al. [4] (0.43 and 0.31) in Egypt. While for ^{40}K, the present study reported lower values than those reported by Gaffar, et al. [27] (1.63) in Malaysia, Ibikunle, et al. [8] (26.59) in south western Nigeria, and Mohannad and Khalil [9] (1.70) in Palestine. However, Harb, et al. [4] reported lower transfer factor (1.06) in Egypt as compared to the present study. The significance of higher TF values is that dispersed radionuclide might be deposited in the soil and transfer to plants via the root's uptake or direct aerial deposition of fallout radionuclides. Ingestion of such plants poses radiation risk to the host communities, which constitute important route of internal exposure.

Findings have revealed that the mean ID for the present study is 0.1002mSv/y, which is lower than the world average value of 0.3mSv/y as according to UNSCEAR [11]. This implies that ingestion of such contaminated plants by the public poses little radiological health risk. The result obtained in this study was lower than that reported by Nyanda and Nkuba [28] (2.73mSv/y) in Manyoni region of Tanzania for ingestion of vegetables around mining sites. Adeleke, et al. [20] reported mean ID (0.0216mSv/y) in some parts of Niger and Kaduna States in Nigeria while estimating the annual effective dose due to the ingestion of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs for medicinal plants samples using normalized value of AC. Results from the present study were higher than dose reported by Adeleke, et al. [20]. Although, mobility of radionuclides from soil to plants is a function of the physical and chemical properties of the soil, plant type, and environmental and human factors [29]. ICRP [12] recommend public dose limit of 1mSv/y, accounting for the total contribution from all pathways (Inhalation, Ingestion and External Pathways). However, the mean dose reported in the present study only accounts for the contribution from ingestion pathway due to contaminated plants around mining locations and was below the world average value of 0.3mSv/y as according to UNSCEAR [11].

5. CONCLUSION

The measured AC values of ^{226}Ra, ^{232}Th and ^{40}K in soil and plant samples obtained from four selected mining sites in Adamawa State were used to estimate the TF, alongside ID to the public resulting from consumption of contaminated plants around the study area using IMBA internal dosimetry code. Findings shows that TF values of ^{226}Ra, ^{232}Th and ^{40}K ranges from 0.6387 to 1.3301 with an mean value of 0.9422 for ^{226}Ra; 0.4886 to 1.8322 with mean value of 0.9502 for ^{232}Th; and 0.2081 to 5.1088 with mean value of 1.2483 for ^{40}K respectively. Findings also show higher TF values 1.0411, 1.0908 and 1.1626 for ^{226}Ra, ^{232}Th and ^{40}K observed around Raycon mining site associated with rice and maize corn. Higher TF values 1.2627 and 1.0077 for ^{232}Th and ^{40}K observed around NRC mining site associated with maize corn. Higher TF values 1.8322 and 2.0051 for ^{232}Th and ^{40}K were observed around Ministry mining site associated with Red Guinea Corn. Higher TF values 1.0524, 1.2074 and 5.1088 for ^{226}Ra, ^{232}Th and ^{40}K were observed around AG Vision mining site associated with white Guinea Corn. The significance of higher TF values is that dispersed radionuclide may be deposited in the soil and transfer to plants via the root's uptake or direct aerial deposition of fallout radionuclides. However, ingestion of such plants poses radiation risk to the host communities which constitute important route of internal exposure.

ID resulting from consumption of contaminated plants by the public around mining sites were estimated using IMBA ID computer code. The dose were estimated from the determined AC of ^{226}Ra, ^{232}Th and ^{40}K in plant. The

result shows higher ID from consumption of contaminated plants around mining sites by the host communities and general public. Although, all the doses obtained falls lower than the public dose limit of 1mSv/y, which is the total contribution from all pathways, the result account for only influence from ingestion pathway. Thus, ingestion of such plants constitute important route of internal exposure and poses radiation risk to the host communities and the public.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

REFERENCES

[1] P. P. Haridasan, "Opening address by PP haridasan [NORM VII: 7. International symposium on naturally occurring radioactive material, Beijing (China), In Naturally Occurring Radioactive Material (NORM VII)," in *Proceedings of An International Symposium*, 2015.

[2] UNSCEAR, *Sources, effects and risk of ionizing radiation. UNSCEAR Annex A: Report to the general assembly, with scientific annexes*. New York, USA: United Nations Scientific Community on the Effects of Atomic Radiation, 1993.

[3] UNSCEAR, "Exposures from natural radiation sources. Forty-Sixth session of UNSCEAR Annex B, Vienna," *United Nations Scientific Committee on the Effects of Atomic Radiation*, vol. 16, pp. 128-142, 2000a.

[4] S. Harb, A. H. El-Kamel, A. I. Abd El-Mageed, A. Abbady, and W. Rashed, "Radioactivity levels and soil-to-plant transfer factor of natural radionuclides from protectorate area in Aswan, Egypt," *World Journal of Nuclear Science and Technology*, vol. 4, pp. 7-15, 2014.Available at: https://doi.org/10.4236/wjnst.2014.41002.

[5] I. C. Okeme, I. V. Sule, N. N. Jibiri, and H. O. Shittu, "Radioactivity concentrations in soil and transfer factors of radionuclides (40K, 226 Ra and 232Th) from soil to rice in Kogi State, Nigeria," *Archives of Applied Science Research*, vol. 8, pp. 34-38, 2016.

[6] O. O. Samuel, T. F. Pascal, A. Cornelus, and M. O. Muyiwa, "Assessment of radioactivity levels and transfer factor of natural radionuclides around Iron and steel smelting company located in Fashina Village, Ile-Ife, Osun State, Nigeria," *Working and Living Environmental Protection*, vol. 15, pp. 241-256, 2018.Available at: https://doi.org/10.22190/fuwlep1803241o.

[7] R. C. Shyamal, A. Rezaul, R. Rezaur, and S. Rashmi, "Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and plants in the Chittagong city of Bangladesh," *Journal of Physical Science*, vol. 24, pp. 95–113, 2013.

[8] S. B. Ibikunle, A. M. Arogunjo, and O. S. Ajayi, "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," *Scientific African*, vol. 3, p. e00062, 2019.Available at: https://doi.org/10.1016/j.sciaf.2019.e00062.

[9] M. J. Mohannad and M. T. Khalil, "Transfer of natural radionuclides from soil to plants and grass in the western North of West bank environment-palestine," *International Journal of Environmental Monitoring and Analysis*, vol. 2, pp. 252-258, 2014.Available at: https://doi.org/10.11648/j.ijema.20140205.14.

[10] G. Shanthia and J. T. Kumaranb, "Advances in applied science research," *Pelagia Research Library*, vol. 4, pp. 283-287, 2013.

[11] UNSCEAR, *Source and effects of Ionizing radiations. Ionising radiation, sources and biological effects. UNSCEAR Report: Annex A. Report to the general assembly, with scientific annexes*. New York: United Nations Scientific Community on the Effects of Atomic Radiation, 2000b.

[12] ICRP, "Guide for the practical application of the ICRP human respiratory tract model. ICRP supporting guidance 3. Annals of the ICRP Retrieved from: https://www.icrp.org/publication.asp?id=ICRP%20Supporting%20Guidance%203.," vol. 32, pp. 17-28, 2002.

[13] A. Birchall, J. Marsh, K. Davis, M. Bailey, N. Jarvis, A. Peach, M. Puncher, M. Dorrian, and A. James, "Using IMBA professional plus to estimate intakes and doses, Change and continuity in radiation protection," in *Proceedings of 7th International Symposium of the Society for Radiological Protection, Cardiff: Society for Radiological Protection*, 2005, pp. 43-48.

[14] U. Ibrahim, T. Akpa, and I. Daniel, "Assessment of radioactivity concentration in soil of some mining areas in Central Nasarawa State, Nigeria," *Science World Journal*, vol. 8, pp. 7-12, 2013.

[15] F. O. Wanjala, D. Otwoma, T. F. Kitao, and N. O. Hashim, "Assessment of natural radioactivity and its radiological impact in Ortum Region in Kenya," in *Conference on Radiation Safety for Sustainable Development. International Nuclear Information System: IAEA Environmental and Earth Science*, 2015, pp. 1-4.

[16] H. O. Shittu, I. O. Olarinoye, A. N. Baba-Kutigi, and S. F. Olukotun, "Determination of the radiological risk associated with naturally occurring radioactive materials (NORM) at selected quarry sites in Abuja FCT," *Nigeria Physics Journal*, vol. 1, pp. 71-78, 2015.

[17] N. Jibiri, S. Alausa, A. Owofolaju, and A. Adeniran, "Terrestrial gamma dose rates and physical-chemical properties of farm soils from ex-tin mining locations in Jos-Plateau, Nigeria," *African Journal of Environmental Science and Technology*, vol. 5, pp. 1039-1049, 2011.Available at: https://doi.org/10.5897/ajest11.245.

[18] A. A. Mbet, U. Ibrahim, and I. Shekwonyadu, "Assessment of radiological risk from the soils of artisanal mining areas of Anka, North West Nigeria," *African Journal of Environmental Science and Technology*, vol. 13, pp. 303-309, 2019.Available at: https://doi.org/10.5897/ajest2019.2691.

[19] S. Mouandza, A. Moubissi, P. Abiama, T. Ekogo, and G. Ben-Bolie, "Study of natural radioactivity to assess of radiation hazards from soil samples collected from Mounana in South-East of Gabon," *International Journal of Radiation Research*, vol. 16, pp. 443-453, 2018.

[20] F. Adeleke, I. Olarinoye, M. Idris, and K. Isah, "Estimation of soil-to-plant transfer factors for 238U, 232Th, 40K and 137Cs radionuclides for some selected medicinal plants in some part of Minna and Kaduna, Nigeria," *Journal of Radiation and Nuclear Applications*, vol. 1, pp. 1-5, 2021.Available at: http://dx.doi.org/10.18576/jrna/010101.

[21] S. O. Oluyide, P. Tchokossa, F. C. Akinyose, and M. M. Orosun, "Assessment of radioactivity levels and transfer factor of natural radionuclides around Iron and steel smelting company located in Fashina Village, Ile-Ife, Osun State, Nigeria," *Working and Living Environmental Protection*, vol. 15, pp. 241-256, 2018.Available at: https://doi.org/10.22190/fuwlep1803241o.

[22] E. Mbong, E. Akpan, and S. Osu, "Soil-plant heavy metal relations and transfer factor index of habitats densely distributed with Citrus reticulata (tangerine)," *Journal of Research in Environmental Science and Toxicology*, vol. 3, pp. 61-65, 2014.

[23] A. Amusan, D. Ige, and R. Olawale, "Characteristics of soils and crops' uptake of metals in municipal waste dump sites in Nigeria," *Journal of Human Ecology*, vol. 17, pp. 167-171, 2005.Available at: https://doi.org/10.1080/09709274.2005.11905775.

[24] P. Andras, A. Lichy, J. Rusková, and L. Matuskova, "Heavy metal contamination of the landscape at the lubietová deposit (Slovakia)," *International Journal of Civil and Environmental Engineer*, vol. 2, pp. 334-355, 2010.

[25] I. I. Udousoro and N. Essien, "Transfer of metals from soil to cucumis sativus fruit and possible health risk assessment under actual field condition," *African Journal of Food, Agriculture, Nutrition and Development*, vol. 15, pp. 10077-1098, 2015.Available at: https://doi.org/10.18697/ajfand.70.15265.

[26] S. K. Alausa, A. O. Olabamiji, and K. Odunaike, "Estimation of natural radionuclides in cattle from a rearing-field at Alabata, Abeokuta Ogun State, Southwestern, Nigeria," *Journal of the Nigerian Association of Mathematical Physics*, vol. 29, pp. 353-362, 2015.

[27] S. Gaffar, M. Ferdous, A. Begum, and S. Ullah, "Transfer of natural radionuclides from soil to plants in North Western parts of Dhaka," *Malaysian Journal of Soil Science*, vol. 18, pp. 61-74, 2014.

[28] P. B. Nyanda and L. L. Nkuba, "Natural radioactivity in vegetables from selected areas of manyoni district in Central Tanzania," *Physical Science International Journal*, vol. 16, pp. 1-10, 2017.Available at: https://doi.org/10.9734/psij/2017/34746.

[29] M. Aktaruzzaman, A. Fakhruddin, M. Chowdhury, Z. Fardous, and M. Alam, "Accumulation of heavy metals in soil and their transfer to leafy vegetables in the region of Dhaka Aricha Highway, Savar, Bangladesh," *Pakistan Journal of Biological Sciences*, vol. 16, pp. 332-338, 2013.Available at: https://doi.org/10.3923/pjbs.2013.332.338.