RESEARCH ARTICLE

Assessment of the levels of natural radionuclides and heavy metals and their transfer factor from soil to crops/vegetables in some agricultural soil in barkin ladi area, plateau state, Nigeria

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ABSTRACT

Radionuclides and heavy metals exist in every human environment as a result of increasing anthropogenic activities. Their pollution of soil, water, and atmosphere represents a growing environmental problem affecting food quality and human health. The samples of soil used for this study was collected from Foron Bisitchi and Mazat communities of Barkin Ladi Area of Plateau state. The samples were analysed using Canberra Model ^{727}Ra Lead Shield Gamma ray Spectrometer with NaI(Ti) detector and ED-XFR. The result shows the range of the concentration of ^{40}K, ^{226}Ra and ^{232}Th in soils as, 203.56 ± 0.80 Bq/Kg to 217.39 ± 0.54 Bq/Kg, 69.39 ± 0.16 Bq/Kg to 98.07 ± 0.88 Bq/Kg and 69.52 ± 0.79 Bq/Kg to 97.88 ± 0.67 Bq/Kg respectively while that of the vegetables/crops vary from 151.75 ± 0.48 Bq/Kg to 271.39 ±0.53 Bq/Kg, 60.76 ± 0.35 Bq/Kg to 80.57 ± 0.64 Bq/Kg and 34.05 ± 0.90 Bq/Kg to 90.16 ±0.59 Bq/Kg respectively. The concentrations of Cr, Mn, Ni, Cu, Zn and Zr in the soil ranges from 1,083 mg/kg -2,380.00 mg/kg, 1,006.79 mg/kg-2,709.00 mg/kg, 235.70 mg/kg-707.40 mg/kg, 1,156.00 mg/kg-2,288.00 mg/kg, 0.00 mg/kg- 560.10 mg/kg and 4,440 mg/kg- 7,770.00 mg/kg respectively. In the vegetables/crops, the ranges of Cr, Mn, Ni, Cu, Zn and Zr Cr are 1,360.00 mg/kg-6,9360.00 mg/kg, 2,012.40 mg/kg-10,062.00 mg/kg, 353.70 mg/kg-943.20 mg/kg, 2,307.20 mg/kg-22,248.00, 1,043.90 mg/kg-9,636.00 and 0.00 mg/kg-1,258.00mg/kg respectively. The radionuclides highest TF of 0.99 was recorded in potato while the least with 0.44 was recorded in cabbage. Likewise, the heavy metals recorded the highest TF of 38.57 in spinach with the least as 0.086 also in spinach. The result is found to be higher than the maximum permissible limit except for 40K which is lower. Almost all the TF are greater than 0.5 which is an indication that there is high uptake of the metals by the crops and vegetables. From the result obtained, it is evident that both the soil and the vegetables are polluted with the radionuclides and heavy metals. The soil is therefore not good for agricultural purposes unless the soil undergoes remediation.

Key Words: *Soil; Heavy metals; Radionuclides; Transfer-factor*

INTRODUCTION

Agriculture has been the backbone of the economy of many developing countries. Many countries in Africa have laid down policies on the provision of sustainable food security. When people have sufficient food to eat, many of the nutrition-related problems are avoided and healthy citizens are available to work for the growth of their economies.

Soil is the main medium for plants, animals and human beings to grow and develop. A wide range of human activities such as mining, transportation, waste disposal, phosphate fertilizer application on agricultural soils as well as industrial activities could also be the cause of the occurrence of threats to the health of the soil . Soils contaminated with radionuclides lose their ability to produce good quality crops and thus can be classified as degraded. The issues related to the degradation of radioactively contaminated soils are being considered as an exceptional type of chemical contamination, with additional, specific features related to ionizing radiation. Heavy metals when present in high concentrations are hazardous contaminants in food and the environment as they are non-biodegradable having long biological half-lives. The implications associated with metal (embracing metalloids) contamination are of great concern, particularly in agricultural production systems due to

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their increasing trends in human foods and the environment. Environmental contamination by heavy metals has become a worldwide problem in recent years due to the fact that heavy metals unlike some other pollutants are not biodegradable. Consequently, they are not detoxified but are bioaccumulated in the environment. Soil pollution by heavy metals has serious health implications especially with regards to crops/vegetables grown on such soils. Heavy metals occupy a special position in soil chemistry because they play very important physiological roles in nature. Generally, the topsoil layer contains the largest amount of pollutants. The contaminant concentration in soil mainly depends on the adsorption properties of soil matter. The solubility of heavy metal ions in the soil is mainly influenced by many factors such as pH, conductivity, and moisture content, higher levels of radionuclide/heavy metals concentration in crops, vegetables, and water have an adverse effect on the health of people exposed to these radionuclides/heavy metals (WHO, 2007) [1-5].

The Transfer Factor (TF) is a value used in the evaluation studies on the impact of routine releases of radionuclides/heavy metals into the environment for most important agricultural products. The soil to plant transfer factor is regarded as one of the most important parameters in the environmental safety assessment needed for nuclear facilities. This parameter is necessary for environmental transfer models which are useful in the prediction of the radionuclide concentrations in agricultural crops for assessment of dose to man IAEA (1994). This work is therefore aimed at assessing the concentration of radionuclides/ heavy metals and their transfer factor from soil to vegetables/crops cultivated in some parts of Barkim-Ladi area in Plateau state, Nigeria [6-9].

MATERIALS AND METHODS

Materials/Equipment

The materials that were used for the research work are: Canberra Model 727/727R Lead Shield Gamma-ray Spectrometer with NaI(Ti) detector, EDX 3600B-Energy Dispersive X-ray Fluorescence spectrometer, Jiangsu Skyray Information Technology Co. Ltd. China Oven Gallenham England, Beakers, Mortar, and pestle.

Area of study

This study was carried out in some parts of Barkin Ladi, a Local Government Area of Plateau State. A total of (7) soil and 7 vegetables/crops samples were collected for radionuclides and (4) soil samples with (4) vegetables/crops samples for heavy metals analysis. The samples were taken from Mazat, Bistchi, and Foron districts.

Sample collection

At each sampling point, about 0.50 kg of the soil sample was collected from a depth of about 0 cm- 15 cm from the surface of the soil, using a clean stainless-steel spoon at a distance of 1m away from each other, and within an area of one square meter from each sampling site. The vegetables were also collected directly from the farm land where the soil was collected.

Sample analysis

Analysis for the radionuclides was achieved by weighing the sample and transferring to radon-impermeable cylindrical plastic containers of uniform size (70 mm height by 60 mm diameter) and was sealed for about 30 days. This was done in order to allow Radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy. The samples were placed symmetrically on top of the detector and measured for a period of 29000 seconds. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to the Compton scattering of higher peaks and other background sources from the total area of the peaks. The use of ED-XRF was employed in the analysis of the heavy metals. ED-XRF spectrometry is an elemental analysis technique with broad applications in science and industry. XRF is based on the principle that individual atoms, when excited by an external energy source, emit x-ray photons of characteristic energy or wavelength. By counting the number of photons of each energy emitted from a sample, the elements present may be identified and quantitated.

TransferFactor(TF)

Transfer Factor (TF) is a useful parameter for radiological assessment. It is defined as the steady-state concentration ratio between one physical situation and another. As a case in point, it is the ratio of the concentration of an element in dry vegetation to that in dry soil. Equation (1) will be used to determine the transfer factor between vegetables and soil as illustrated below:

$$TF = \frac{C_v}{C_s} \quad (1)$$

Where TF is Transfer Factor of soil to vegetables, Cv is the concentration of radionuclides in Bq/kg dry vegetables weight. Cs is the concentration of radionuclides in Bq/kg dry soil weight (Tables 1-3).

TABLE 1
Results of the activity concentration of ^{40}K, ^{226}Ra and ^{232}Th n soils and vegetables/crops bq/kg and their transfer factor

Sample ID	^{40}K	^{226}Ra	^{232}Th	TF		
				^{40}K	^{226}Ra	^{232}Th
R1	211.99 ± 0.27	76.62 ± 0.59	81.08 ± 0.55	0.99	0.80	0.93
RP1	209.55 ±0.11	65.59 ± 0.44	75.06 ± 0.24			
R2	271.39 ± 0.54	98.07 ± 0.88	93. 26 ± 0.43	0.96	0.82	0.78
RP2	260.39 ±0.53	80.57 ± 0.64	72.82 ± 0.51			
F1	239.54 ± 0.48	88.81 ± 0.47	83.47 ± 0.31	0.60	0.73	0.65
VF1	153.15 ± 0.38	64.99 ± 0.23	54.06 ± 0.55			
B2	219.33 ± 0.91	70.31 ± 0.59	77.18 ± 0.18	0.69	0.93	0.44
VB2	151.75 ± 0.48	65.44 ± 0.11	34.05 ± 0.90			
B1	204.37 ± 0.16	74.10 ± 0.59	69.52 ± 0.79	0.79	0.81	0.84
VB1	162.86 ± 0.64	60.76 ± 0.35	58.07 ± 0.71			
K1	209.14 ± 0.80	69.39 ± 0.16	90.16 ± 0.98	0.97	0.89	0.87
PK1	203.56 ± 0.80	62.72 ± 0.52	78.64 ± 0.59			
K2	230.16 ± 0.75	82.43 ± 0.36	97.88 ± 0.67	0.91	0.88	0.90
PK2	210.80 ± 0.75	72.29 ± 0.28	87.67 ± 0.62			
Permissible limits	412	35	45			

TABLE 2
Results of concentration of heavy metals in Soil and Vegetables in Mazat, Bisitchi and Foron (mg/kg)

Sample ID	Cr	Mn	Ni	Cu	Zn	Zr
FS1	2,288.00	1,006.79	235.73	576.80	ND	7,770.00
VF1	3,876.00	10,062.00	943.20	22,248.00	9,636.00	666.00
BS1	1,156.00	1,470.60	235.80	3,625.60	321.20	7,252.00
VB1	1,360.00	417.96	550.20	2,307.20	1,043.90	1,258.00
RS1	1,176.00	1,935.00	707.40	741.60	321.20	4,440.00
RP1	6,868.00	2,012.40	2,122.20	6,839.20	1,606.00	ND
KS1	1,700.00	2,709.00	314.40	906.40	560.10	7,474.00
KP1	6,936.00	2,310.00	353.70	8,076.20	1,606.00	ND
Permissible limit	50.00	2000.00	60.00	100.00	300.00	

TABLE 3
Transfer factor of the heavy metals from soil to vegetables

Sample ID	Cr	Mn	Ni	Cu	Zn	Zr
FV1	1.69	10.00	4.00	38.57	-	0.086
BV1	1.18	0.28	2.34	0.64	3.25	0.17
RP1	5.84	1.04	3.00	9.23	5.00	-
KP1	4.08	0.85	1.12	8.91	2.87	-
Permissible limit	2.00	500.00	0.03	73.00	100.00	

RESULTS & DISCUSSION

The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th expressed in Bq/Kg for the samples obtained from some agricultural farmland in Mazat and Bisitchi District in Barkin Ladi. The soil and vegetables samples were collected directly from the farmland in Ramabohan, Kaper, and Bisitchi. The result of the analysis is as presented in table 1 above. The result of ^{40}K, ^{226}Ra, and ^{232}Th in the soil samples ranges from 203.56 ± 0.80 to 217.39 ± 0.54, 69.39 ± 0.16 to 98.07 ± 0.88, and 69.52 ±0.79 to 97.88 ± 0.67 respectively. The result obtained from this study were compared with other studies in Nigeria and elsewhere in the world on agricultural soil samples and was found to be lower than those of Jibiri et al. (2011) and Masok et al. (2015) in some ex-tin mining locations of Jos Plateau, Nigeria. A similar study in Toro show a similar result for ^{232}Th while ^{226}Ra was lower compared to those of this study, ^{40}K was found to be higher than the result obtained in this study. This study also has results higher than those of Babatunde et al. (2019), Araromi et al. (2016), Rahamat and Lihan, (2022), in Malaysia. the high concentrations of the radionuclides in the present studies may be as a result of artisanal mining activities taking place close to the farm lands. ^{232}Th and ^{226}Ra concentration were higher than the recommended world average of 45 Bq/Kg and 35 Bq/Kg respectively while the concentration of ^{40}K in all the samples were lower than the world average of 420 Bq/Kg (UNSCEAR, 2000). The concentration of the radionuclides in the vegetables for ^{40}K, has values that ranges from 151.75 Bq/Kg ± 0.48 Bq/Kg in Ramabohan Potato Farmland 1 (RP1) to 271.39 Bq/Kg ± 0.53 Bq/Kg in Spinach collected from Bisitchi farm land 2 (VB2), ^{226}Ra ranges from 60.76 ± 0.35 in spinach from bisitchi farm land 1 (VB1) to 80.57 ± 0.64 in potato collected from Ramabohan farm land 2 (RP2), ^{232}Th varies from 34.05 Bq/Kg ± 0.90 Bq/Kg in spinach collected from bisitchi farm 2 (VB2) to 90.16 Bq/Kg ± 0.59 Bq/Kg in potato collected from Kaper farm land 1 (KP1)[6-9] . The result obtained are higher than those reported by Aswood et al. (2013) and Ademola, (2019). The transfer of the radionuclides from soil to vegetables is also as presented in Table1.

The results recorded a very high transfer factor in all the radionuclides analysed. ^{40}K recorded the lowest TF of 0.60 in spinach cultivated in Foron whereas the highest TF of 0.99 was recorded in potato cultivated in Ramabohan. The high TF value of potassium is not a risk because it has an insignificant contribution to internal dose as ^{40}K content is homeostatically controlled, UNSCEAR, (2000). 226Ra also range from 0.73 to 0.93 whereas the transfer factor of

232Th range from 0.44 to 0.93. The TF is higher in potato than those of the spinach analyzed in the two districts. Uptake of the isotopes from the soil by the vegetables depends on various interrelated soil properties, including texture, clay content, cation exchange capacity, exchangeable cations, pH, and organic matter content. It also varies depending on the chemical and physical forms of the radionuclides, plant species and stage of growth.The concentrations (Mg/kg) of Cr, Ni, Cu, Zn, Mn Zr and V in both soil and vegetable samples are presented in Table 2 above. The data revealed that all the analyzed heavy metals accumulated by the vegetable and soil at different concentrations. Zr has a higher concentration in both the soil and vegetables compared to the other metals. The concentration of Zr in the study area has the highest concentration of 7,770.00mg/kg in Foron Siol (FS1) whereas the least was recorded in Ramabohan Soil (RS1), likewise, the spinach cultivated in Foron (FV1) recorded 666.00 mg/kg with spinach in Bisitchi recoding 1,258.00 mg/kg respectively. Zircon often contains uranium and thorium and other radioactive elements in it. Earlier studies on the natural radioactivity on beach sand has proven that Zr contains 0.1 to 0.5% uranium and thorium Van Schumus, (1995) and Bergamini, (1985).

Chromium regulates carbohydrate, nucleic acid and lipoprotein metabolism. This metal also potentiates insulin action. In addition, Cr activates several enzymes. However, chronic exposure of Cr may damage the liver, kidney, and lungs, Malaysian Food Regulation (1985). The range of Cr in the soil is 2,288.00 mg/kg to 1,156.00 mg/kg. This is higher than that of Daniel et al. (2014). The concentration of Cr in the vegetables also range from 6,936.00 mg/kg in potato sample KP1 to 1,360.00 mg/kg in spinach sample BV1. This value is higher than the 2 mg/kg permissible limit while the concentration of Cr in the soil is higher than the allowable limits of 60 mg/kg .

The concentration of Nickel in the soil and vegetable sample range from 707.40 mg/kg to 235.73 mg/kg and 2,122.20 mg/kg to 353.70 mg/kg respectively these values are higher compared. Nickel has high concentration in the vegetables as compared with WHO permissible limit of 0.03 mg/kg. The highest concentration is found in Potato cultivated around Ramabohan (RP1) which is 2,122.20 mg/kg. The concentrations of Nickel in the vegetable were higher than those of the soil. Several factors such as the application of pesticides, chemical fertilizer or the artisanal mining activity taking place around the sampling point could be responsible for it. Nickel is known to be a carcinogen. A mean daily ingestion of 8.69 x 10-9 mg/day of nickel will stand a cancer risk.

The concentration of Zn in the soil of the study area range from Not Detected (ND) to 560.10 mg/kg whereas the concentration in the vegetables varies from 1,043.90 mg/kg to 9,636.00 mg/kg. Concentrations of Zn found in contaminated soils frequently exceed to those required as nutrients and may cause phytotoxicity. Zn concentrations in the range of 150 mg/kg-300 mg/kg have been measured in polluted soils. High levels of Zn in soil inhibit many plant metabolic functions and will result in retarded growth and cause senescence. Zinc toxicity in plants limited the growth of both root and shoot. The Zn concentrations in this study exceed the permissible limits of 60 mg/kg highly detrimental to human health than too much Zn in the diet. The recommended dietary allowance for Zn is 15 mg/day for men and 12 mg/day for women Agency for Toxic Substances and Disease Registry, but high concentration of Zn in vegetables may cause vomiting, renal damage, cramps, etc.

Manganese is a very essential trace heavy metal for plants and animals' growth. Its deficiency produces severe skeletal and reproductive abnormalities in mammals. High concentration of Manganese (Mn) causes hazardous effects on lungs and brains of humans. The concentration of Mn in the soil of the study area has the highest value of 2,709.00 mg/kg recorded in Kaper Soil (KS1) while the least is 1,006.79 recorded in Foron soil FS1. Mn content in the vegetables varies from 417.96 mg/kg in spinach collected from Bisitchi VB1 to 10,062.00 mg/kg in cabbage collected in Foron VF1. The concentration of Mn is more in the vegetables than in the soil except for vegetables in Bisitchi where the value is higher in the soil than the vegetable. Higher proportions of Mn in the vegetable samples are another confirmation of the high absorption of Mn by the tissues from the soils on which they grow and other non-anthropogenic sources.

Copper is an essential micronutrient involved in a number of biological processes needed to sustain life. However, it can be toxic when present in excess. The concentration of Cu in the soil varies from 576.80 mg/kg to 3, 625.60 mg/kg which is higher than those reported by Mokgolele and Likuku, (2016). This value exceeds the maximum permissible limit of 100mg/kg for Cu in horticultural soils. The results of Cu in vegetables in this study has a very high value of 22,248.00 mg/kg in spinach VF1 while the lowest was recorded in VB1 as 2,307.20 mg/kg. All results recorded in the vegetable samples are greater than the soil. The maximum permissible concentration of Cu in plants recommended by the World Health Organization (WHO) is 73 mg/kg.

Generally, the transfer factor expresses the bioavailability of metal at a particular position on a species of plant. All the samples have significant differences in the transfer factors of metals relative to the availability of the same metals in the soil. The transfer factor as seen in Table 3 are very high. The TF in Cr ranges from 1.18 to 5.84, Mn from 0.85 to 10.00, Ni from 1.12 to 4.00, Cu from 0.64 to 38.57, Zn from Null to 5.00 respectively. Cu has the highest TF of 38.57 in spinach cultivated in Foron, and the least TF which is Mn is recorded in cabbage cultivated in Bisitchi. When the transfer factor is less than one, it may be a probability that soil is the main source of metal bioaccumulation in plants. However, it is more revealing that, when the value is higher than one, the total concentrations of metals in soil do not necessarily correspond to the metal bioavailability in plants. The bioavailability of heavy metals depends on a number of physicochemical properties such as pH, organic matter contents, cation exchange capacity, redox potential, soil texture, and clay contents.

CONCLUSION

The concentration of the radionuclides ^{40}K, ^{226}Ra, and ^{232}Th as well as the heavy metals Cr, Mn, Ni, Cu, Zn, and Zr were analysed from soil in agricultural farmland and vegetables/crops in Barkin Ladi Local Government Area of Plateau State. The transfer factor was also determined. The result of the analysis shows that the concentrations of $_{226}$Ra and ^{232}Th in the soil and vegetables were all above the recommended limits whereas the concentration of ^{40}K was below the maximum permissible limits. All the heavy metals analysed also show higher concentrations above the recommended standard. The TF was all above 0.5 except for Zr where the TF is 0.086. This is an indication that there is a high rate of absorption of both the radionuclides and heavy metals by the crops and vegetables. The soil is thus said to be polluted with both heavy metals and radionuclides.

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