INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue V May 2023

Determination of the Concentrations of Radionuclides and Heavy Metals and Their Transfer Factor from Soil to Crops/Vegetables in Some Agricultural Soils in Barkin Ladi Area, Plateau State, Nigeria

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DOI: https://doi.org/10.51584/IJRIAS.2023.8514

Received: 29 April 2023; Revised: 15 May 2023; Accepted: 20 May 2023; Published: 20 June 2023

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 were collected from Foron Bisitchi and Mazat communities of Barkin Ladi Area of Plateau state. The samples were analyzed using Canberra Model 727/727R 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 to 217.39 ± 0.54 Bq/Kg, 69.39 ±0.16 to 98.07 ± 0.88 Bq/Kg and 69.52 ±0.79 to 97.88 ± 0.67 Bq/Kg respectively. The concentrations of Cr, Mn, Ni, Cu, Zn and Zr in the soil ranges from 1,083 - 2,380.00 mg/kg, 1,006.79 - 2,709.00 mg/kg, 235.70 - 707.40 mg/kg, 1,156.00 - 2,288.00 mg/kg, 0.00 - 560.10 mg/kg and 4,440 - 7,770.00 mg/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 ^{40}K 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

I. Introduction

Most developing countries depend on Agriculture for their economic development. 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.

Plants, animals, and humans all grow and develop primarily in soil (Shi *et al.*, 2014). The occurrence of threats to the health of the soil may also be the result of a wide range of human activities like mining, transportation, waste disposal, industrial activities and application of phosphate fertilizer to agricultural soils (Wang *et al.*,2014: Mokgolele and Likuku 2016).

According to Aleksakhin (2009), radionuclide contaminated soils lose their ability to produce high-quality agricultural crops and are considered degraded. Aleksakhin (2009), also stated that the issues associated with the degradation of radioactively contaminated soils are being considered a distinct kind of chemical contamination with additional, particular characteristics associated with ionizing radiation.

Because they are non-biodegradable and have long biological half-lives, heavy metals in high concentrations are hazardous contaminants in food and the environment (Heidarieh *et al.*, 2013). The ramifications related with metal (embracing metalloids) pollution are of extraordinary concern, especially in horticultural creation frameworks (Kachenko and Singh, 2006), because of their rising patterns in human food sources and the climate. Due to the fact that heavy metals, unlike some other pollutants, are not biodegradable, environmental contamination by heavy metals has become a global issue in recent years (Bazrafshan *et al.*, 2015). As a result, they are bioaccumulated in the environment rather than detoxified.

Soil contamination by heavy metals has serious wellbeing suggestion particularly with respect to crops/vegetables grown on such soils (Steffana *et al.*, 2017). Due to their significant physiological roles in nature, heavy metals hold a special place in soil chemistry (Akpoveta *et al.*, 2010). The topsoil layer typically contains the most pollutants. The adsorption properties of soil matter play a major role in determining the concentration of contaminants in soil. Numerous factors, including pH, conductivity, and moisture content, have the greatest impact on the solubility of heavy metal ions in soil. (Rakesh and Raju 2013), higher levels of radionuclide/heavy metals concentration in crops, vegetables and water have adverse effect on the health of people exposed to these radionuclides/heavy metals (WHO, 2007).

A value called the transfer factor (TF) is used in studying of the effects of routine releases of heavy metals and radionuclides into the environment for the majority of important agricultural products (Adjirackor *et al.,* 2017). One of the most crucial parameters in the environmental safety assessment required for nuclear facilities is the soil-to-plant transfer factor. Environmental transfer models, which are helpful in predicting the concentrations of the radionuclide in agricultural crops for the purpose of assessing the dose to humans, require this parameter (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.

II. Materials and Methods

2.1 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.

2.2 Area of Study

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

2.3 Sample collection

At each sampling point, about 0.50 kg of the soil sample was collected from a depth of about 0- 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.

2.3.1. Sample analysis

The radionuclides were analyzed by weighing the sample and placing it in uniformly sized, radon-impermeable, cylinder-shaped plastic containers that measured 70 mm in height by 60 mm in diameter and were sealed for approximately 30 days. Prior to gamma spectroscopy, this was done so that Radon and its short-lived offspring could reach secular radioactive equilibrium.

For 29000 seconds, the samples were placed symmetrically on top of the detector and measured. The counts caused by Compton scattering of higher peaks and other background sources were subtracted from the total area of the peaks to calculate the net area under the corresponding peaks in the energy spectrum.

The utilization of ED-XRF was utilized in the examination of the heavy metals. An elemental analysis method with numerous applications in science and industry is ED-XRF spectrometry. XRF depends on the rule that singular particle, when invigorated by an outside energy source, discharge x-beam photons of attributes energy or frequency. It is possible to identify and quantify the elements that are present in a sample by counting the number of photons that are released from each energy.

2.4 Transfer Factor, TF.

A useful parameter for radiological evaluation is the transfer factor (TF). The steady-state concentration ratio between two physical conditions is how it is defined. A good illustration of this is the ratio of an element's concentration in dry vegetation to its concentration in dry soil. The transfer factor between vegetables and soil will be determined using Equation 1 (Wang *et al*.,1997; Chibowski and Gladyz, 1999), as shown in the following:

$$TF = \frac{C_v}{C_s} \quad \text{......} 1$$

Where TF is transfer factor of soil to vegetables, C_v is the concentration of radionuclides in Bq/kg dry vegetables weight. *Cs* is the concentration of radionuclides in Bq/kg dry soil weight.

III. Results and Discussion:

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue V May 2023

Table 1: Results of the Activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in 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			

n=3

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	

Key: R= Ramabohan Potato, F= Foron Spinach, B = Bisitchi Cabbage, K= Kaper Potato, V= vegetables, S= Soil.

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	-

IV. Discussion

The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th expressed in Bq/Kg for the samples obtained from some agricultural farm land in Mazat and Bisitchi District in Barkin Ladi . The soil and vegetables samples were collected directly from the farm land in Ramabohan, Kaper and Bisitchi. The result of the analysis is 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 and 35 Bq/Kg respectively while the concentration of ^{40}K in all the samples were lower than the world average of 420Bq/Kg (UNSCEAR, 2000). The concentration of the radionuclides in the vegetables for ^{40}K, has values that ranges from 151.75 ± 0.48 Bq/Kg in Ramabohan potato farm land 1 (RP1) to 271.39 ±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 ± 0.90 Bq/Kg in spinach collected from bisitchi farm 2 (VB2) to 90.16±0.59 Bq/Kg in potato collected from Kaper farm land 1 (KP1). 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 are also as presented in Table1 above.

The results recorded very high transfer factor in all the radionuclides analyzed. ^{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 will not cause any serious risk because it has negligible contribution to internal dose as ^{40}K content is homeostatically controlled, UNSCEAR, (2000). ^{226}Ra also range from 0.73 to 0.93 whereas the transfer factor of ^{232}Th range from 0.44 to 0.93. The TF is higher in potato than those of the spinach analyzed in the two districts. The texture, amount of clay, cation exchange capacity, exchangeable cations, pH, and organic matter content of the soil all play a role in vegetables' ability to absorb isotopes from it. According to Carini and Bengtsson (2001), it also varies depending on the plant species, growth stage, and chemical and physical forms of the radionuclides.

The concentrations (Mg/kg) of Cr, Ni, Cu, Zn, Mn Zr, and V in vegetable and soil samples are shown in Table 2 above. All of the analyzed heavy metals accumulated in varying concentrations in the vegetable and soil, are according to the data. Zr has the 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 666.00mg/kg with spinach in Bisitchi recoding 1,258.00 mg/kg respectively. Zircon often contains uranium and thorium and other radioactive element in it. Earlier studies on the natural radioactivity on beach sand have proven that Zr contains 0.1 to 0.5% uranium and thorium Van Schumus, (1995) and Bergamini *et al.* (1985).

Chromium regulates carbohydrate, nucleic acid and lipoprotein metabolism. This metal also potentiates insulin action (Yap *et al.*, 2010). 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 ranges from 6,936.00mg/kg in potato sample KP1 to 1,360.00mg/kg in spinach sample BV1. This value is higher than the 2 mg/kg permissible limit (Abdalla, 2003) while the concentration of Cr in the soil is higher than the allowable limits of 60 mg/kg (Siti *et al.*, 2014)

The concentration of Nickel in the soil and vegetable sample range from 707.40mg/kg to 235.73 mg/kg and 2,122.20mg/kg to 353.70mg/kg respectively these values are higher compared to (Daniel *et al.*, 2014). 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 2,122.20mg/kg. The concentrations of Nickel in the vegetable were higher than those of the soil. Several factors such as 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, (Haribala *et al.*, 2017).

The concentration of Zn in the soil of the study area range from not detected (ND) to 560.10mg/kg whereas the concentration in the vegetables varies from 1,043.90 mg/kg to 9,636.00mg/kg. Concentration of Zn found in defiled soils regularly surpass to those expected as supplements and may cause phytotoxicity. In polluted soils, Zn concentrations between 150 and 300 mg/kg have been measured (Devries *et al.*, 2002). Numerous metabolic functions of plants are inhibited by high levels of zinc in the soil, resulting in senescence and slowed growth. According to Choi *et al.* (1996) plants with zinc toxicity experienced restricted root and shoot growth. This analyzed Zn concentrations go above the WHO/FAO (2007) limit of 60 mg/kg, which is much worse for human health than eating too much Zn. According to the Agency for Toxic Substances and Disease Registry, men should consume 15 mg of zinc per day and women should consume 12 mg, but vegetables high in zinc can cause vomiting, damage to the kidneys, cramps, and other symptoms (ATSDR, 2007).

Manganese is a very important trace metal for the growth of animals and plants. Mammalian skeletal and reproductive abnormalities are severe when it is absent. According to Jarup (2003), high levels of manganese (Mn) pose a threat to human lungs and brains. The soil in the study area has the highest Mn concentration, with a value of 2,709.00mg/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 417.96mg/kg in spinach collected from Bisitchi VB1 to 10,062.00mg/kg in cabbage collected in Foron VF1. The concentration of the Mn is more in the vegetables than in the soil except for vegetable in Bisitchi where the value is higher in the soil than the vegetable. Another sign that the tissues of vegetables absorb a lot of Mn from their soils and other non-anthropogenic sources is the presence of higher Mn concentrations in the samples.

Copper is a micronutrient that is necessary for many biological processes that are necessary for life to continue. However, excessive amounts of it can be harmful (De Roman *et al.*, 2011). The soil's Cu concentration ranges from 576.80 mg/kg to 3,625.60 mg/kg, which is higher than Mokgolele and Likuku's (2011) findings. According to Kabata-Pendias (2001), these values are higher than the maximum permissible limit of 100 mg/kg for Cu in horticultural soils. This study found that spinach VF1 had a very high value of 22,248.00mg/kg of Cu, while VB1 had a very low value of 2,307.20mg/kg. All of the results in the vegetable samples are higher than those in the soil. The World Health Organization (WHO) recommends a maximum permissible concentration of Cu in plants of 73 mg/kg (Chiroma *et al.*, 2012). In most cases, the bioavailability of a metal at a specific location on a plant species is expressed by the transfer factor.

The transfer factors of metals between the samples and the soil's availability of the same metals differ significantly. As can be seen in Table 3, the transfer factor is extremely high. Cr has a TF range of 1.18 to 5.84, Mn has a TF of 0.85 to 10.00, Ni has a TF of 1.12 to 4.00, Cu has a TF of 0.64 to 38.57, and Zn has a TF of Null to 5.00, respectively. The spinach grown in Foron has the highest TF of 38.57, while the cabbage grown in Bisitchi has the lowest TF which is in Mn.

Soil may be the primary source of metal bioaccumulation in plants when the transfer factor is less than one. However, the fact that the total concentrations of metals in the soil do not necessarily correspond to the metal bioavailability in plants when the value is greater than one is more revealing. The pH, organic matter content, cation exchange capacity, redox potential, soil texture, and clay content all have an impact on heavy metal bioavailability (Mwegoha and Kihampa, 2010).

V. 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 analyzed from soil in agricultural farm land 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 analyzed also show higher concentrations above the recommended standard. The TF were all above 0.5 except for Zr where the TF is 0.086. This is an indication that there is high rate of absorption of both the radionuclides and heavy metals by the crops and vegetables. The soil is thus said to polluted with both the heavy metals and radionuclides.

Acknowledgements

The authors are grateful to Tertiary Education Trust Fund (**TETFUND**) for the sponsorship of this research.

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ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue V May 2023

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