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Determination of Activity Concentration and Soil-Plants Transfer Factor for Some Crops of Selected Cultivated Soils in Sokoto East Senatorial District, Sokoto State Nigeria

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Abstract **Original Research Article**

This study determined the activity concentration of naturally occurring radionuclides (Ra-226, Th-232, and K-40) in selected crops and their corresponding cultivated soils in Sokoto East Senatorial District, Sokoto State, Nigeria, with the aim of evaluating soil–plant transfer behavior and potential radiological implications. Soil and plant samples were collected from different farming locations and analyzed using standard gamma-ray spectrometry techniques. The activity concentrations of the radionuclides varied across sampling sites, with soil samples consistently exhibiting higher values than plant samples, indicating limited uptake by crops. Among the radionuclides analyzed, K-40 recorded the highest activity concentrations in both soils and plants due to its natural abundance and essential role in plant physiology, while Ra-226 and Th-232 showed comparatively lower concentrations. The calculated soil–plant transfer factors revealed generally low values for Ra-226 and Th-232, whereas higher transfer factors were observed for K-40, reflecting its greater mobility and bioavailability. The results obtained were within internationally reported natural background levels, suggesting no significant radiological health risk to the local population through consumption of the studied crops. This study provides baseline data on natural radioactivity in agricultural soils and food crops in the study area and contributes to environmental radiological assessment and food safety monitoring in northwestern Nigeria.

Keywords: Activity, Soil, Plants, Transfer and Concentration.

INTRODUCTION

Since its beginning, the Earth's crust has contained radionuclides, and human beings are exposed to natural as well as artificial radioactivity. Natural radioactivity mainly arises from primordial radionuclides, such as ^{40}K, ^{232}Th, and ^{226}Ra, whereas artificial radioactivity arises from human activities, such as in the generation of electricity from nuclear power plants, nuclear medicine, nuclear weapon tests etc,[1]. The main external sources of irradiation of the human body are thought to be the background radiation that originated as a result of the decay of naturally occurring radionuclides materials (NORMs). NORMs are "Materials which may contain any primordial radionuclides or radioactive elements as they occur in nature, such as potassium, uranium, and thorium, that are disturbed by human activities" Terrestrial radionuclides are common in the soil, rocks, water, and building material used for dwellings [2]. Only those primordial radionuclides with half-lives large enough (larger than or equal to the age of the earth) and their progenies present in sufficient amounts to contribute significantly to population exposure [3]. Investigations on terrestrial natural radiation have received particular attention worldwide and led to extensive surveys in many counties [4]. They mainly serve as baseline data of natural radioactivity such that man made possible contaminations can be detected and quantitatively determined. They can further be used to assess public dose rates and to perform epidemiological studies. The results obtained in each country can be exploited to enrich the world's data bank, which is highly needed for evaluating worldwide average values of radiometric and dosimetric quantities [5].

Generally speaking, terrestrial radionuclides are present in the soil in varying amounts depending on the nature of the bedrock accumulated during the soil formation and the soil properties. Besides several other factors, these radionuclides may present in soil with high or low concentrations, but their presence in any quantity is threatening. Various sources transfer radiation into the human body in several ways. The radionuclides deposited on soils and different parts of crop plants, and their uptake by plants and water contamination, are the main critical sources of exposure that should be seriously considered., It was generally discovered that terrestrial pathways were more significant than aquatic ones [6]. Moreover, the soil-plant-man pathway is one of the main environmental processes that result in radioactive intake by humans [7] Hence, understanding NORMs in soil systems is essential for improving radioactivity determination, enhancing the estimation of radiation hazards [8], and establishing appropriate scientific knowledge of the levels of radionuclides in the soil and their relationship with the uptake rate of the cultivated plants [9].

The present study reports the concentrations of radium-226, thorium-232, and potassium-40 isotopes in some consumable crops collected from different cultivated soil of Sokoto east senatorial district. In addition, the transfer of these radionuclides from soil to plants was estimated by calculating the transfer factor (TF) value.

Over the years, some work on the transfer or pathway mechanism of naturally occurring radionuclides to plants and human population have been reported but data are still very scarce in Nigeria particularly in Sokoto east senatorial district.

Research Objectives

1. To measure activity concentrations of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) present in the soil and some plant consumed as staple by the populations in Sokoto east senatorial district;
2. To determine the soil-to-plant Transfer Factors of ^{226}Ra, ^{232}Th and ^{40}K of some plant consumed as staple by the populations in Sokoto east senatorial district;
3. To statistically analysed the data using one way ANOVA analysis.
4. To make the result interpretation available to the local government, state and other stakeholder such as (MDAs, Ministries and Agencies) for prompt action if need be.

LITERATURE REVIEW

Many studies have been conducted on radiological characteristics in different part of the world [10] conducted the TF of the radionuclides ^{238}U, ^{232}Th, and ^{40}K using a HPGe detector for several crops collected from some farms in the suburbs of Baghdad and Najaf City, Iraq. The results showed that the value of TF for ^{238}U, ^{232}Th, and ^{40}K are (0.32, 0.70, and 3.44), respectively. The average value of TF for ^{238}U and ^{232}Th were (0.23) and (0.2), which are lower than the allowed value, but the (1.85) reported for ^{40}K was higher than that.

The activities of ^{238}U, ^{232}Th, and ^{40}K were carried out for some crops and corresponding soils in Erbil City, north of Iraq, by [11] using a HP germanium detector. The results showed that the activity levels range for ^{226}Ra, ^{232}Th, and ^{40}K in cultivated soils ranged from 11.94 Bq.kg^{-1} to 18.24 Bq.kg^{-1}, and from 8.80 Bq.kg^{-1} to 12.36 Bq.kg^{-1} and from 247.65 Bq.kg^{-1} to 338.26 Bq.kg^{-1}, respectively. While for plant crops were (0.20–1.45) Bq.kg^{-1} for 226Ra, (0.11–0.48) Bq.kg^{-1} for ^{232}Th, and (68.07–1355.36) Bq.kg^{-1} for ^{40}K. The transfer factor values were found to be in the ranges of (0.011-0.087), (0.011–0.046), and (0.201–5.130) for ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

Transfer factors of ^{238}U, ^{232}Th, and ^{40}K for several crops in some cultivated soils in The Nahrawan region, Baghdad, Iraq, were evaluated by [12] using a high-purity germanium detector. TF for ^{238}U, ^{232}Th, and ^{40}K were found within the range of (0.00019-0.24), (0.09-1.24), and (0.9-5.1), respectively.

[13] measured the soil-to-plant transfer factor of some radionuclides (^{238}U, ^{232}Th, and ^{40}K) using instrumental activation analysis techniques in different locations in Malaysia. The TF's values were found to be in the range of (0.003-0.473), (0.003-0.548), and (0.430-1.479) for ^{238}U, ^{232}Th, and ^{40}K, respectively.

Justification

Radiation exposure can result in stochastic health effect, the greater incidence of cancer in population exposed to ionizing radiation indicates that the probability or risk of developing cancer is proportional to the level of radiation at low and high dose rate of exposure [12].

The results from this work could help to know the exposure of the public from ingestion of the crops; and therefore, the dose received by the public who are consuming the crops in the study location, and the cancer risk associated with the exposure.

Description of the study area

Sokoto East Senatorial District is located in the eastern part of Sokoto State in north-western Nigeria, approximately between latitudes 12°30′N and 13°45′N and longitudes 5°00′E and 6°30′E, and it shares boundaries with parts of Zamfara State as well as the Niger Republic. The district lies within the Sudan–Sahel savannah zone, characterized by flat to gently undulating plains, sandy soils, and seasonal rivers that support agricultural activities. It is predominantly rural with a fairly large population made up mainly of Hausa and Fulani ethnic groups whose socio-economic life revolves around farming and trading. Agriculture is the main occupation, practiced through both rain-fed and irrigation systems, particularly around river valleys and dam areas. Major crops cultivated in the district include millet, sorghum, rice, maize, cowpea, and groundnut, which are produced for household consumption and commercial purposes, contributing significantly to local food security and the economy of Sokoto State.

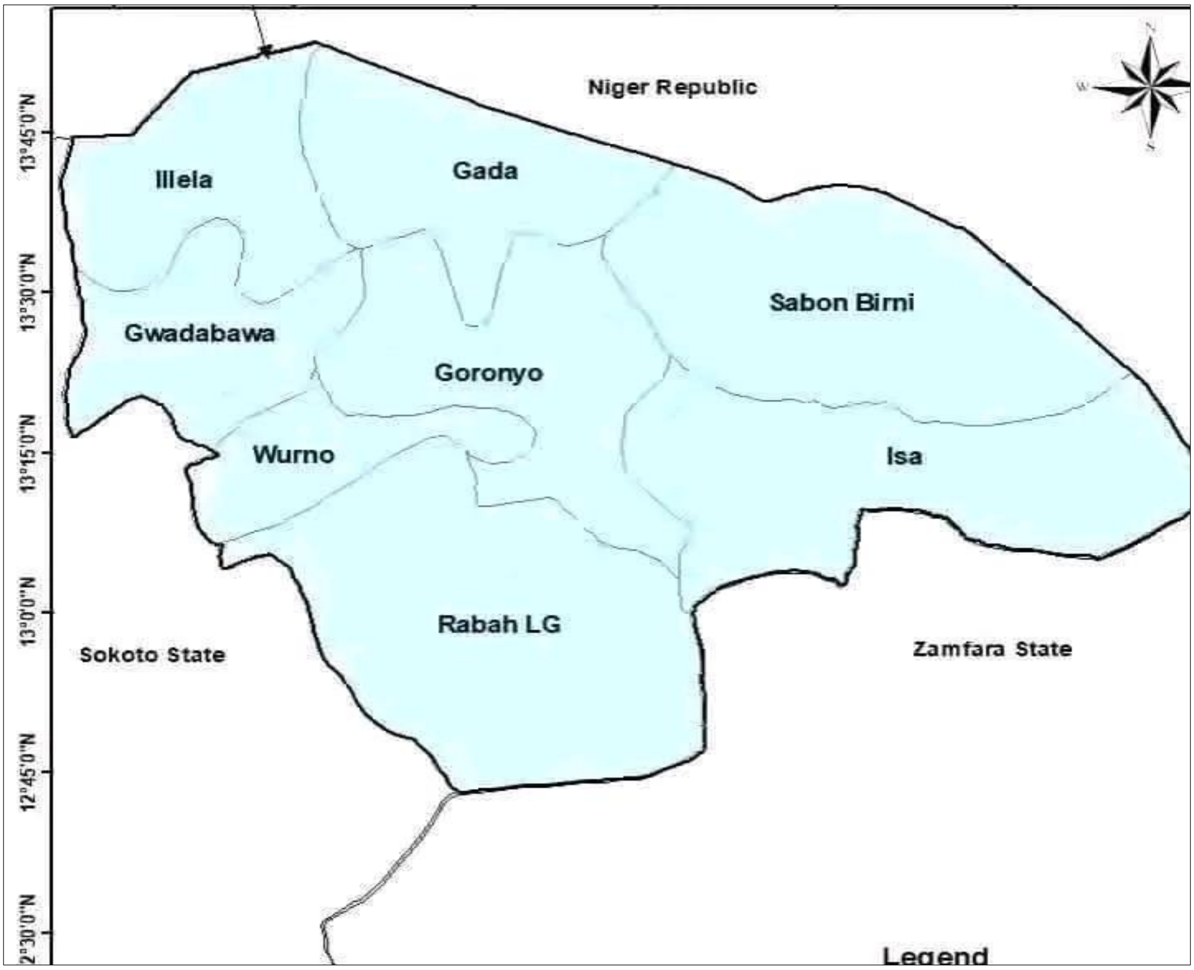

Figure 1: Map of the study area

Sampling and Processing

In this study, plants and soil samples were collected from different agricultural land within the study location, representing a large contributor to food in the zone. The soil samples were collected from the area with a diameter of 20 cm surrounding the plant roots at a depth of 5-15 cm with an average of 1 kg for each sample using an iron shovel. Crop samples, including okra, onions, tomatoes, watermelon, sweet potato, carrot, cassava, garlic, garden egg and organic pepper, were collected from the sample points of the soil by gathering edible parts of vegetables equivalent to about 2 kg weight for each sample. The collected soil and corresponding vegetable samples were packed in labelled polythene bags (Every bag carry a sample code and lcation), to be sealed, and transferred to the lab for treatment. The first step of processing is preparing the samples for counting; plant samples will be cut into small parts and dried in room air for a few days, then in an electric oven at 60℃ for 4 hours to get rid of water. After drying, the samples will be grounded to a fine powder using a manual grinder few days, then in an electric oven at (60 ºC) for (4 hours) to get rid of water. After drying, the samples will be grounded to a fine powder using a manual grinder. On the other hand, soil samples will firstly air dried, then genteelly smashed by a hummer before putting in the oven to remove any remaining moisture. The drying process will take (8 hours) at (80 ºC), and then sieved through a 2 mm sieve. Finally, both crops and soil samples of (500 g) dry-weight will be placed into cylindrical plastic containers, and the containers will be selected to be identical in size and shape to increase counting accuracy and to reduce self-absorption for that specific geometry [13]. The containers will then be tightly sealed using silicon and adhesive tape and left for four weeks to reach the secular equilibrium between the radionuclides and their progenies.

Samples Analysis

The radioactivity measurements will be performed using a high-resolution gamma spectroscopy system, the system consisting of a HP Ge detector “crystal diameter of 65.4 mm, thickness of 52.3 mm, the operating voltage of 2500 V” with an efficiency of 50 %

and 2.2 keV-FWHM energy resolution at the 1332 keV photons at 60 ºC, surrounded by a cylindrical shield of lead with a thickness of 10 cm, with the inner surface covered by three layers of aluminium, cadmium, and iron with 1 mm thickness for each to reduce the background. The detector is connected to an ICS-PCI card with a (1024-4096) channel analyser, amplifier, and analogue-to-digital converter.

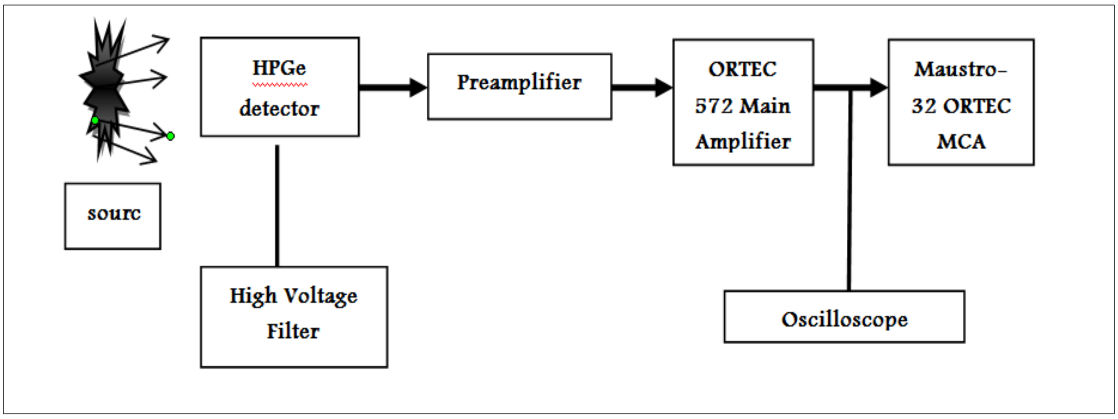

Figure 2: Block Diagram of Higher Purity Gamma spectrometry system

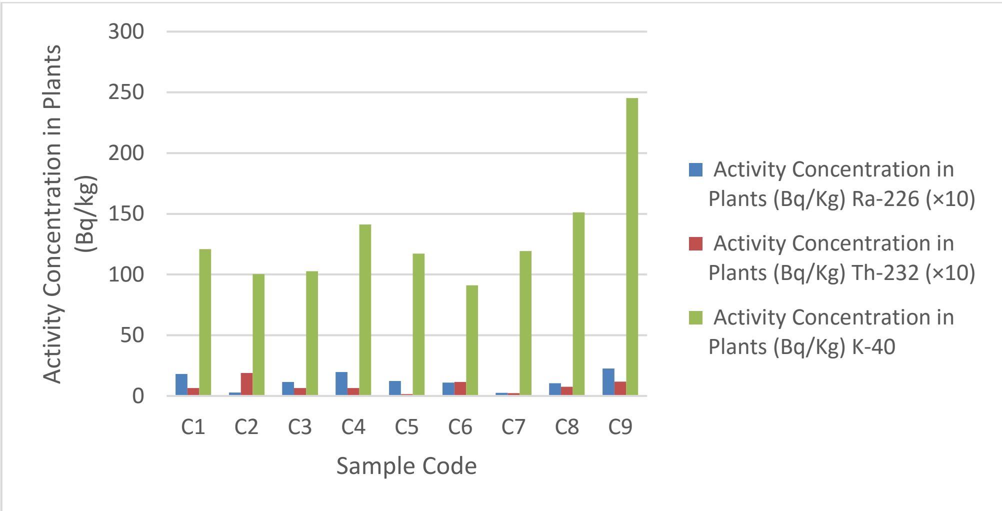

Figure 3: A bar diagram of activity levels of natural radionuclides Ra-226, Th-232 and K-40 of different plant samples in Sokoto east senatorial district

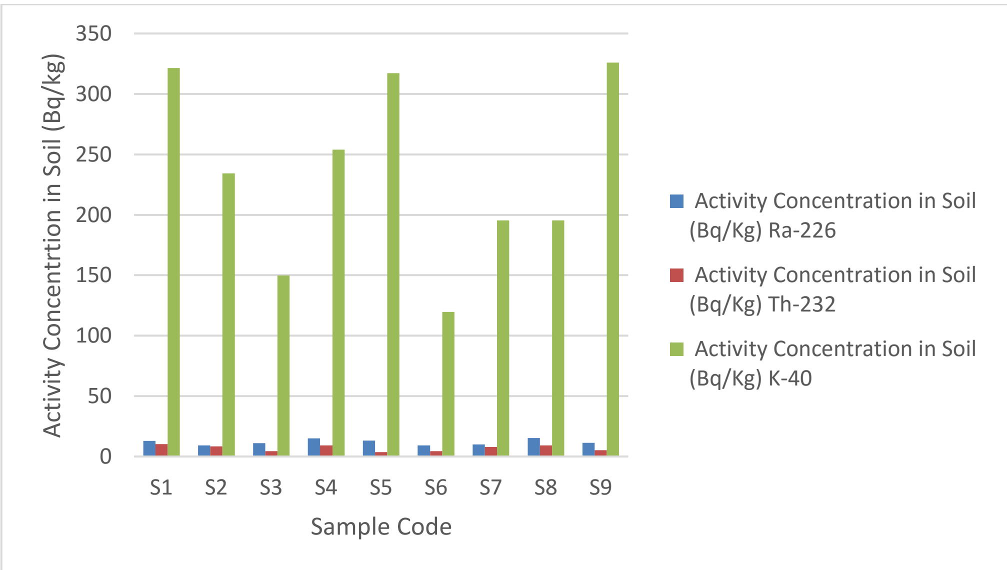

Figure 4: A bar diagram of activity levels of natural radionuclides Ra-226, Th-232 and K-40 of different soil samples in Sokoto east senatorial district

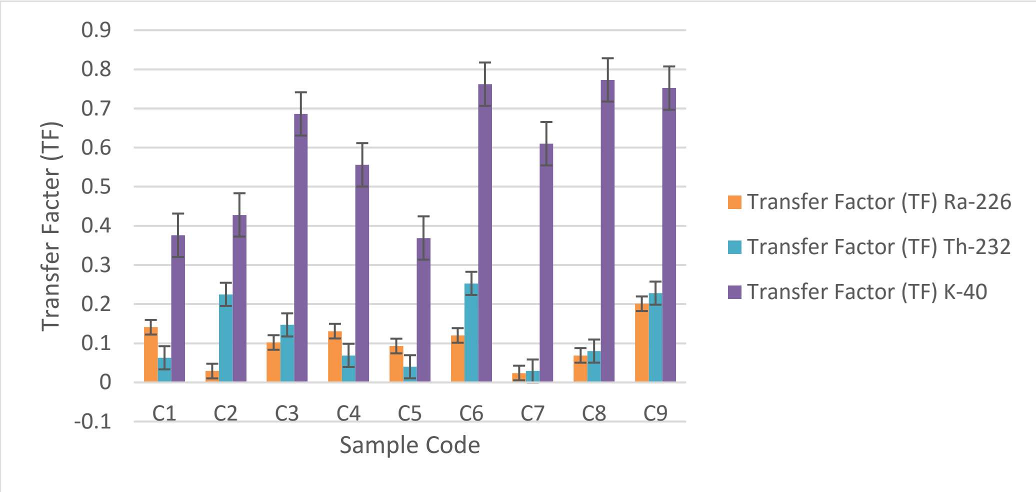

Figure 5: Transfer Factor (TF) of natural radionuclides Ra-226, Th-232 and K-40 of different soil samples in Sokoto east senatorial district

The symbol for plants C1 – C9 are given in Table 1.

Table 1: Activity Concentration of Natural Radionuclides in Soil, Plants and Calculated TF

Sample Code	Activity Concentration in Plants (Bq/Kg)			Activity Concentration in Soil (Bq/Kg)			Transfer Factor (TF)		
	Ra-226	Th-232	K-40	Ra-226	Th-232	K-40	^{226}Ra	^{232}Th	^{40}K
C1	1.81 ± 0.20	0.65 ± 0.81	120.95 ± 2.17	12.81 ± 0.72	10.22 ± 0.98	321.36 ± 2.17	0.14	0.06	0.38
C2	0.27 ± 0.54	1.89 ± 0.18	100.37 ± 2.02	9.27 ± 0.54	8.37 ± 0.18	234.37 ± 2.02	0.03	0.23	0.43
C3	1.14 ± 0.16	0.65 ± 0.58	102.81 ± 2.15	11.14 ± 0.06	4.42 ± 0.58	149.86 ± 2.65	0.1	0.15	0.69
C4	1.97 ± 0.25	0.64 ± 0.27	141.17 ± 2.05	14.94 ± 0.25	9.25 ± 0.27	253.77 ± 2.85	0.13	0.07	0.56
C5	1.24 ± 0.75	0.15 ± 0.16	117.23 ± 2.53	13.24 ± 0.75	3.75 ± 0.96	317.22 ± 2.00	0.09	0.04	0.37
C6	1.10 ± 1.09	1.15 ± 0.14	91.14 ± 1.33	9.16 ± 0.79	4.53 ± 0.84	119.57 ± 1.04	0.12	0.25	0.76
C7	0.25 ± 0.11	0.23 ± 0.21	119.24 ± 2.33	10.05 ± 0.19	7.88 ± 0.43	195.41 ± 2.51	0.02	0.03	0.61
C8	1.05 ± 0.21	0.75 ± 0.79	151.27 ± 2.11	15.16 ± 0.91	9.33 ± 0.79	195.47 ± 2.41	0.07	0.08	0.77
C9	2.26 ± 1.11	1.17 ± 0.04	245.40 ± 2.16	11.22 ± 0.71	5.13 ± 0.44	325.94 ± 2.05	0.2	0.23	0.75
Mean	**1.23 ± 0.49**	**0.80 ± 0.35**	**132.17 ± 2.09**	**11.88 ± 0.54**	**6.98 ± 0.60**	**234.79 ± 2.18**	**0.1**	**0.13**	**0.59**

The detector's energy and efficiency will be performed using standard multi-gamma reference sources. The curves were obtained by fitting the experimental efficiencies for each sampling density and corrected for attenuation and self-absorption [2]. The radioactivity levels of the radionuclides in the investigated samples will be conducted from the following gamma-ray lines: (351.93) keV (35.6%) from ^{214}Pb, and (609.32) keV (45.49%) and (1120.294) keV (14.92 %) from ^{214}Bi will be used for determination of ^{226}Ra, ^{232}Th concentration will be obtained using (238.632) keV (43.6 %) from ^{212}Pb, (583.19) keV (85 %) from ^{208}Tl, and (911.204) keV (25.8 %) from ^{228}Ac. In comparison, the content of ^{40}K will be estimated using the gamma-ray line (1460.822) keV (10.66 %) [16]; [17]. To evaluate the specific activity of the samples, each sample will be counted for 12000 s, and the net activity will be obtained by deducting the background and calculated using the following equation [18]; [19].

$$A_i = \frac{N}{t \times \varepsilon(E_\gamma) \times I_\gamma \times m} \quad [1]$$

Where N is the peak area, t is the measurements time, $\varepsilon(E_\gamma)$ is the efficiency of detection, I_γ is the abundance of energy E_γ, and m is the sample weight.

3.4 Transfer Factor

Transfer factor (TF) is a steady-state concentration between two different physical conditions, an important factor for radiological evaluation [20]. The ratio of the activity concentration in the plants in (Bq.kg^{-1}) to the concentration in the corresponding soil in (Bq.kg^{-1}) was used to calculate the transfer factor as follows [21].

$$TF = \frac{C_v\ (BqKg^{-1})}{C_s\ (BqKg^{-1})} \quad [2]$$

Where TF is the transfer factor, Cv is the radionuclide concentration in the dry weight of vegetables (Bq/kg), and Cs is the concentration of the radionuclides in the dry weight of soil (Bq/kg).

RESULTS AND DISCUSSION

Measurement of Radioactivity

The levels of radioactivity in nine (9) types of vegetables and corresponding soils in Sokoto east senatorial district were performed using High Purity Germanium detector HP (Ge). The activity of ^{226}Ra, ^{232}Th and ^{40}K was estimated in sixty three (63) vegetable samples, comprising okra(C1), onions(C2), tomatoes(C3), watermelon(C4), sweet potato(C5), carrot(C6), cassava(C7), garlic(C8), and organic pepper(C9), with an average of seven (7) samples per crop and S1, S2, S3, S4, S5, S6, S7, S8 and S9 as their corresponding soil samples respectively. The activity concentration of Radium-226 in plant samples varied from a minimum value of 0.25 ± 0.11 Bq/kg cassava to a maximum value of 2.26 ± 1.11 Bq/kg organic pepper, with a mean value of 1.23 ± 0.49 Bq/kg. This variation indicates differences in soil–plant uptake processes, which may be influenced by soil properties, plant species, and radionuclide bioavailability.

For Thorium-232, the activity concentration in plants ranged between a minimum of 0.15 ± 0.16 Bq/kg sweet potatoes and a maximum of 1.89 ± 0.18 Bq/kg onions. The average activity concentration was found to be 0.80 ± 0.35 Bq/kg. Generally, the lower values of Th-232 compared to Ra-226 suggest limited mobility and lower uptake of thorium by plants.

The activity concentration of Potassium-40 in plant samples showed significantly higher values compared to Ra-226 and Th-232. The minimum value recorded was 91.14 ± 1.33 Bq/kg carrots, while the maximum value was 245.40 ± 2.16 Bq/kg organic pepper. The mean activity concentration of K-40 in plants was 132.17 ± 2.09 Bq/kg. This relatively high concentration is expected, as potassium is an essential nutrient required for plant growth.

In soil samples, the activity concentration of Ra-226 ranged from a minimum of 9.16 ± 0.79 Bq/kg (S6) to a maximum of 15.16 ± 0.91 Bq/kg (S8), with an average value of 11.88 ± 0.54 Bq/kg. These values reflect the natural background levels of radium in the study area.

The activity concentration of Th-232 in soil varied between a minimum value of 3.75 ± 0.96 Bq/kg (S5) and a maximum value of 10.22 ± 0.98 Bq/kg (S1). The mean concentration was 6.98 ± 0.60 Bq/kg, indicating moderate thorium content in the soils.

For K-40, soil activity concentrations were notably higher than those of Ra-226 and Th-232. The minimum value was 119.57 ± 1.04 Bq/kg (S6), while the maximum value was 325.94 ± 2.05 Bq/kg (S9). The average activity concentration of K-40 in soil was 234.79 ± 2.18 Bq/kg, consistent with the natural abundance of potassium in soils.

However, the results show that soil samples recorded higher activity concentrations of all radionuclides compared to plant samples. Among the radionuclides analyzed, K-40 exhibited the highest activity concentration in both plants and soils, followed by Ra-226 and Th-232. The observed variations in minimum, maximum, and mean values across sampling locations suggest that local geological characteristics and soil composition play a significant role in controlling radionuclide distribution and uptake by plants.

The transfer factor (TF) values of the natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K indicate varying degrees of radionuclide transfer from soil to plants across the sampled locations. For radium-226, TF values range from a minimum of 0.02 cassava to a maximum of 0.20 organic pepper, with a mean value of 0.10, reflecting moderate uptake that is influenced by its chemical similarity to calcium, soil pH, cation exchange capacity, and strong adsorption to clay and organic matter, which can limit its mobility. Thorium-232 shows TF values between 0.03 cassava and 0.25 carrot, with an average of 0.13, indicating generally low transfer due to its poor solubility and strong binding to soil particles, particularly clay minerals and organic matter, although localized soil conditions may slightly enhance its availability in some samples. In contrast, potassium-40 exhibits the highest TF values, ranging from 0.37 sweet potato to 0.77 garden egg, with a mean of 0.59, which is expected since potassium is an essential plant nutrient that is actively absorbed through root transport mechanisms, making it more bioavailable than radium and thorium. Overall, the mean TF values follow the order ^{40}K > ^{232}Th > ^{226}Ra, demonstrating that potassium has the greatest potential for soil-to-plant transfer, while radium and thorium exhibit relatively limited uptake due to their non-essential nature and strong retention in soil matrices.

CONCLUSION

Based on the determination of activity concentration and soil–plant transfer factor of natural radionuclides in selected crops and cultivated soils of Sokoto East Senatorial District, Sokoto State, Nigeria, the study revealed the presence of Ra-226, Th-232 and K-40 in both soil and plant samples at varying levels. The activity concentrations of all the radionuclides were consistently higher in soil samples than in the corresponding plant samples, indicating limited but measurable uptake of radionuclides by crops from the soil. Among the radionuclides investigated, K-40 recorded the highest activity concentration in both soils and plants, reflecting its natural abundance in the environment and its essential role in plant metabolism, while Ra-226 and Th-232 showed relatively lower concentrations due to their lower mobility and bioavailability. The calculated soil–plant transfer factors further demonstrated that the uptake of Ra-226 and Th-232 by crops was generally low, whereas K-40 exhibited comparatively higher transfer values, consistent with its biological significance. Overall, the measured activity concentrations and transfer factors suggest that the cultivated soils and crops in the study area are within normal natural background levels and do not pose any significant radiological health risk to the local population through consumption of agricultural produce. However, the observed spatial variations highlight the influence of soil characteristics and local geology on radionuclide distribution and transfer, emphasizing the importance of continuous monitoring to ensure environmental and food safety in the study area.

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