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Measurement of Transfer Factors from Soil-to-Plant/Food Crop of Naturally Occurring Radionuclide Materials (NORMs) in Nigeria: A Review

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Abstract

One of the most crucial factors in the environmental safety assessment for the local and global communities, situated either in normal background areas or around nuclear facilities, is the uptake of radionuclides from soil by plants, which is typically stated as soil-to-plant Transfer Factor (TF) or Transfer Coefficient (TC). Such a metric, which can be defined as the ratio of radioactivity unit per dry crop mass to that of unit per dry soil mass, is necessary for environmental transfer models, which help to estimate the radionuclide concentrations in agricultural crops and calculate the dose exposure to people. In this article, a number of research studies conducted by scholars in Nigeria, published in both national and international journals, were compiled and reviewed for the purpose of providing an integrated and synthesized overview of the current state of knowledge on NORMs' transfer factors in Nigeria. The activity concentrations of ^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th and ^{238}U were measured by different research groups using gamma ray spectrometry coupled with either NaI(Tl) or HPGe detector. The activity concentrations of natural radioactivity in soils samples were generally higher than the values recorded in plant and food crop samples in almost all the research studies considered in the review. About 79% of the values of soil-to-plant transfer factor of ^{40}K in all the studies under review were greater than the recommended value, while the values of transfer factors reported for ^{232}Th and ^{238}U were all greater than the recommended values.

Keywords: Measurement, Transfer factor, NORMs, Soil-to-Plant, Nigeria

INTRODUCTION

Natural radionuclides are parts of every environment un-inhabited and inhabited by human beings. Even human bodies contain Naturally Occurring Radioactive Materials (NORMs). NORMs are categorized as being of terrestrial or cosmic origin. Humans are exposed to both internal and external radiation from these natural sources. The dose of radioactivity to which humans are exposed depends directly on the level of radioactivity in the environment they live in and the food/water they consume. All soil used anywhere in the world for agricultural purposes contains radionuclides to a greater or lesser extent. Typical soils

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(IA89a) contain approximately 300kBq/m^3 of ^{40}K to a depth of 20cm. By far, the largest source of natural radiation exposure comes from varying amounts of Uranium and Thorium in the soil around the world. These contaminations posed significant hazardous effects on man. This radionuclide and others are then taken up by crops/plants and transferred to food, leading to a concentration in food of between 50 and 150 BqKg^{-1}.

Every food has some small amount of radioactivity in it. Inhalation, ingestion, and other means of contact (both direct and indirect) are major pathways of exposure of humans to radiations from radioactive sources of both natural and artificial origin. The common radionuclides in foods are potassium-40 (^{40}K), radium-226 (^{226}Ra), and uranium-238 (^{238}U) and the associated progeny (Eisenbud & Gesell, 1997). Radionuclides ingestion through food consumption are major radiation pathways for long term health considerations and contribute significantly to the average radiation doses to various organs and tissues in the human body (Jibiri *et. al*., 2007). The potential damage from an absorbed dose depends on the type of radiation and the sensitivity of different tissues and organs. At higher doses, radiation can impair the functioning of tissues and organs as well as produce acute effects such as skin redness, hair loss, radiation burns or acute radiation syndrome. If radiation dose is low but delivered over a long period of time, the risk is substantially lower, however, there is still a risk of long-term effects such as cancer which may appear years later after the exposure.

The uptake of radionuclides from the soil by the plants, normally expressed as soil-to-plant transfer factor (TF), or transfer coefficient (CF), or concentration ratio (CR), is defined as the ratio of the activity concentration in a plant part (in BqKg^{-1} dry weight) to the activity concentration in the soil (BqKg^{-1} dry weight), (Ehlken & Kirchner, 2002; Baeza *et. al*., 2005). The knowledge of natural radionuclide activity concentration levels and their mobility in the environment is of great interest in several scientific fields. Migration and accumulation of contaminants (including radionuclides) in the soil-plant system is complex. The assessment models usually make use of TF to estimate the transportation of radionuclides through the food chain. TF describes the amount of radionuclide expected to enter different parts of a plant from the soil and it is regarded as one of the most important parameters in the environmental safety assessment for nuclear facilities (IEAE, 1994). It is essential for environmental transfer models, which are useful in the prediction of radionuclide concentration in agricultural crops for estimating dose impact to human being (Chakraborty *et. al*., 2013).

Over the years, many studies have been carried-out on concentrations and transfer (or pathway) mechanism of NORMs to plants and human populace, yet data are still sparse in this area, especially Transfer Factors, in Nigeria. This article tries to compile the data reported by many scholars on studies carried-out on soil-to-plant transfer factors of NORMs for the purpose of assessment of public dose rates, performance of epidemiological studies and maintaining reference-data records, which may assist in ascertaining possible changes in environmental radiations due to industrial and other human actions and/or inactions.

STUDIES ON NORMs AND THEIR TRANSFER FACTORS IN NIGERIA

This section contains summary/extracts of findings from studies carried out by different scholars on soil-to-plant Transfer Factor of NORMs in various plant components. The activity concentrations of natural and artificial radionuclides (especially Caesium, Cs), were evaluated in soils, and their soil-to-plant transfer factors in *Amaranthus hybridus* plants determined in eighteen (18) locations from six states (Lagos, Ogun, Oyo, Osun, Ondo and

Ekiti) in south-western part of Nigeria by Ibikunle *et. al.,* (2019) using a co-axial type, High Purity Germanium (HPGe) detector. From the study, the average specific activities of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in the soil samples ranged from BDL – 1545.07 (mean: 393.73 BqKg^{-1}), 8.53 – 160.37 (mean: 52.91 BqKg^{-1}), 13.54 – 295.24 (mean: 76.79 Bqkg^{-1}) and, BDL – 2.15 (mean: 1.44 BqKg^{-1}) respectively, while the mean specific activities of ^{40}K, ^{226}Ra and ^{232}Th in plant samples ranged from 681.90 – 9221.05 (mean: 3,271.66 BqKg^{-1}), BDL – 57.73 (mean: 25.88 BqKg^{-1}) and, BDL – 48.56 (mean: 19.90 BqKg^{-1}) respectively. ^{137}Cs was not detected in any of the plant samples. Values of Radium equivalent activity (Ra_{eq}), the external (H_{ex}), and the internal (H_{in}) hazard indices estimated in the study ranged from 28.47 to 701.53 BqKg^{-1}, 0.08 to 1.89, and 0.10 to 2.33, with mean values of 191.34 BqKg^{-1}, 0.52, and 0.66 respectively. The average soil-to-plant Transfer Factors for ^{40}K, ^{226}Ra and ^{232}Th obtained in the study ranged from 0.44 – 107.76 (mean: 26.58), 0.12 – 1.95 (mean: 0.62) and, 0.04 - 1.44 (mean: 0.39) respectively. The mean absorbed dose (D), and annual outdoor effective dose equivalent (AEDE) in soil samples obtained in the study were 86.44 nGy.h^{-1} and 0.1060 mSv.y^{-1} respectively. The mean annual effective dose obtained (0.1060 mSv.y^{-1}) is higher than both the world average value of 0.07 mSv.y^{-1} and the international recommended standards of 0.1 mSv.y^{-1} by the World Health Organization (WHO, 2006). The excess lifetime cancer risk (ELCR) evaluated in the study ranged from 7.35×10^{-5} to 1.36×10^{-3}, with a mean of 3.71×10^{-4}, which is equally higher than the world average value 2.9×10^{-4} reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000). However, regression analysis, from the study, showed that there was no linearity in the relationship between activity concentration of radionuclides in soil and in plant grown on the particular soil, and hence the soil-to-plant transfer factor is not a function of soil radioactivity.

Ononugbo *et. al.,* (2019) assessed the uptake and distribution of NORMs in Cassava crops from Nigerian Government farms in four cities: Agbor, Ogwashi-Uku, Ibusa and Igbodo of Delta state, using Gamma-ray spectroscopy with Sodium iodide [NaI(TI)] detector. The average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil samples reported in the study ranged from 92.07 – 689.28 (mean: 413.64 ± 21.22), 5.37 - 64.93 (mean: 54.43 ± 3.22) and, BDL – 928.15 (mean: 561.67 ± 2.21) BqKg^{-1} respectively, while the mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th recorded in cassava crop samples ranged from 403.91 – 795.53 (mean: 746.08 ± 0.48), BDL – 60.13 (mean: 24.83 ± 10.87) and, 576.13 – 955.46 (mean: 859.41 ± 2.47) BqKg^{-1} respectively. The transfer coefficients for ^{40}K, ^{226}Ra and ^{232}Th varied from 0.68 – 4.50; 0 – 1.81 and 0 – 3.41 respectively. The mean estimated values of radium equivalent activity (Ra_{eq}), absorbed dose rate (D), annual effective dose rate (AEDE), internal hazard index (H_{in}) and excess life cancer risk (ELCR) of soil samples from the study include: 1009.27 BqKg^{-1}, 346.50 nGy.h^{-1}, 1.51 mSv.y^{-1}, 2.78×10^{-3} and 3.92×10^{-3} respectively. The estimated values of Ra_{eq}; D; AEDE, H_{in} and ELCR gotten from the study were higher than their corresponding permissible values of 370 BqKg^{-1}, 55 nGy.h^{-1}, 1.0 mSv.y^{-1} 1.0 and 0.29×10^{-3} recommended by various radiation control agencies.

The mean values of H_{in} and H_{ex} obtained, which are greater than unity, were indications that the consumers of agricultural products in the study area face radiological health risk. In addition, the average gonad dose estimated value of 2943.90 mSv.y^{-1} and the annual effective dose in majority of the samples used in the study were above the acceptable values of 300 mSv.y^{-1}and 1.0 mSv.y^{-1}, making the usage of soil in the study area a threat to general health of both inhabitants and consumers of crops grown in the area.

Oluyide *et. al.,* (2018) investigated the radioactive levels and transfer factor of natural radionuclides in soil, plant and water around Iron and steel smelting company situated in

Fashina village, Osun state in Nigeria, where an Iron and Steel smelting company is situated as a study area (and Opa, located 12 Km from the study area as the control area), using a Sodium-Iodide [NaI(TI)] detector. The average activity concentrations of natural radioactivity obtained in the study for ^{238}U, ^{232}Th and ^{40}K, in soil samples, ranged from 7.28 – 20.18 (mean: 12.14 ± 4.17), 6.28 – 41.22 (mean: 23.23 ± 7.67) and, 92.85 – 537.28 (mean: 270.14 ± 61.79) $BqKg^{-1}$ respectively in the study area, while in the control area, it ranged from 5.98 – 11.82 (mean: 8.64 ± 2.46), 18.16 – 20.31 (mean:19.38 ± 5.30) and, 193.86 – 264.65 (mean: 220.35 ± 42.37) $BqKg^{-1}$ respectively.

The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in food samples reported in the study ranged from 5.27 – 13.13 (mean: 8.56 ± 2.80), 5.12 – 21.15 (mean: 13.17 ± 4.48) and, 53.27 – 124.9 (mean: 89.41 ±24.15) $BqKg^{-1}$ respectively in the study area, while in the control area, the range recorded include, BDL – 10.27 (mean: 8.01 ± 2.45), 3.35 – 9.37 (mean: 6.65 ± 2.53) and, 46.58 – 64.34 (mean: 54.36 ± 16.69) $BqKg^{-1}$ respectively. Similarly, the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water samples in the study area ranged from 4.15 – 12.01 (mean: 7.64 ± 2.90), 4.41 – 13.04 (mean: 10.04 ± 3.31) and, 47.08 – 98.62 (mean: 69.04 ± 15.29) $Bq.L^{-1}$ respectively, while in the control area, it ranged from 7.36 – 11.53 (mean: 9.45 ± 3.48), 9.89 – 11.74 (mean:10.82 ± 3.22) and, 61.96 – 69.83 (mean: 65.90 ± 18.17) $Bq.L^{-1}$ respectively for ^{238}U, ^{232}Th and ^{40}K. The transfer factor, calculated, from soil to food for ^{238}U, ^{232}Th and ^{40}K in the study area also ranged from 0.40 – 0.97 (mean: 0.73), 0.26 – 0.84 (mean: 0.61) and, 0.20 – 0.57 (mean:0.39) $BqKg^{-1}$ respectively in the study area, while in the control area it ranged from BDL – 1.27 (mean: 0.69), 0.17 – 0.48 (mean: 0.32) and, 0.26 – 0.33 (mean: 0.26) $BqKg^{-1}$ respectively. The concentration of ^{238}U, ^{232}Th and ^{40}K in the study area was generally found to be higher than the one recorded in the control area while concentrations of ^{238}U and ^{232}Th were also found to be higher than the recommended limits in some food and water samples. The transfer factor, from soil-to-plant of ^{238}U and ^{232}Th was found to be higher than that of ^{40}K and this was attributed to the industrial activities and hence, deposition of radioactive particles of ^{238}U and ^{232}Th series on the surface of plants in the study area.

Okeme *et. al.*. (2016) carried out a study on radioactivity concentrations, and transfer factors of natural radionuclides from soil-to-rice plant in the rice producing areas: Lokoja and Ibaji of Kogi state, Nigeria, by means of Gamma-ray Spectroscopy using NaI(Tl) detector. The results obtained from the samples in the study areas were equally compared with corresponding values of rice samples obtained in Lokoja and Ibaji markets. In Lokoja, the mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soils samples ranged from 442.17 – 606.82 (mean: 508.86 ± 54.02) 30.85 -57.20 (mean: 41.27 ± 9.31) and, 12.07 – 23.47 (mean: 18.90 ± 4.21) $BqKg^{-1}$ respectively, while in samples of rice collected in the study area, the mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th ranged from: 35.96 – 50.44 (mean: 41.15 ± 5.41), 8.06 – 19.10 (mean: 12.73 ± 3.77) and, 9.01 – 12.98 (mean: 10.36 ± 1.72) $BqKg^{-1}$ respectively. However, the average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in rice samples from Lokoja market were 38.00 ± 10.23, 7.45 ± 2.37 and 9.08 ± 3.04 $BqKg^{-1}$. The transfer factors of ^{40}K, ^{226}Ra and ^{232}Th in Lokoja rice ranged from 0.0755 – 0.0884 (mean: 0.0808), 0.2180 – 0.3910 (mean: 0.3090) and, 0.3967 – 0.9899 (mean: 0.5912) respectively.

Also in Ibaji, the mean concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil samples ranged from 543.23 – 702.09 (mean: 633.54 ± 34.09), 5.85 – 14.46 (mean: 9.81 ± 3.13) and, 6.23 – 13.80 (mean: 11.95 ± 3.79) $BqKg^{-1}$ respectively; and in rice samples harvested in Ibaji, it ranged from 41.55 – 87.89 (mean: 61.01 ± 18.05), 5.73 – 8.00 (mean: 7.28 ± 0.83) and, 5.90 – 13.20 (mean: 9.89 ± 2.59) $BqKg^{-1}$ respectively. In samples of rice procured from Ibaji market, the average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th were 38.71 ± 10.25, 7.94 ± 2.27 and 8.65 ± 2.01 BqKg^{-1}. The transfer factors of ^{40}K, ^{226}Ra and ^{232}Th in Ibaji rice ranged from 0.0592 – 0.1410 (mean: 0.0975), 0.4910 – 0.9795 (mean: 0.8052) and, 0.4912 – 0.9975 (mean: 0.8710) respectively. The values of activity concentrations of ^{40}K reported in Lokoja (508.86 BqKg^{-1}) and Ibaji (639.52 BqKg^{-1}) are higher than the World mean value of 400 BqKg^{-1}, and that of ^{226}Ra recorded in Lokoja (41.27 BqKg^{-1}) is also higher than the world mean value of 35 BqKg^{-1}, this might be due to agricultural practices and the geology of the study areas. The low values of transfer factor might be due to slow transportation (low absorption) of radionuclides by the rice plant.

Ademola (2019) equally probed the activity concentrations of naturally-occurring radioactive materials present in soil, vegetables, and food crops as well as their transfer factors from soil-to-plants in high background (mining) areas in northern parts of Oyo state: Iwere-Ile, Komu, Ofiki and Igbeti, using gamma spectrometry analytical technique. From the study, the average concentration of ^{226}Ra, ^{228}Ra and ^{40}K in soil samples ranged from 20.5 – 32.1 (mean: 25.3 ± 7.1), 18.0 – 35.6 (mean: 26.2 ± 5.0) and, 296.5 – 420.1 (mean: 381.8 ± 16.0) BqKg^{-1} respectively in Iwere-Ile; 20.1 – 30.5 (mean: 25.4 ± 3.1), 34.0 – 43.3 (mean: 39.5 ± 3.8) and, 365.7 – 420.5 (mean: 401.9 ± 25.4) BqKg^{-1} respectively in Komu; it also ranged from 18.1 – 40.5 (mean: 26.5 ± 3.3), 32.3 – 46.2 (mean: 39.2 ± 7.4) and, 350.0 – 442.4 (mean: 394.9 ± 18.6) BqKg^{-1} respectively in Ofiki; and, 20.1 – 35.2 (mean: 26.5 ± 3.5), 30.8 – 44.2 (mean: 38.8 ± 2.5) and, 300.6 – 421.1 (mean: 389.6 ± 18.6) BqKg^{-1} respectively in Igbeti. The mean concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in vegetables in the study areas ranged from 1.9 – 4.3 (mean: 2.8 ± 0.8), 1.3 – 2.5 (mean: 1.7 ± 0.3) and, 61.6 – 100.8 (mean: 85.3 ± 12.0) BqKg^{-1} respectively in Iwere-Ile; 1.2 – 2.0 (mean: 1.6 ± 0.2), 1.2 – 1.9 (mean: 1.5 ± 0.6) and, 32.3 – 100.6 (mean: 73.2 ± 5.6) BqKg^{-1} respectively in Komu; 1.6 – 2.6 (mean: 2.0 ± 0.6), 1.1 – 2.0 (mean: 1.5 ± 0.8) and, 46.1 – 160.2 (mean: 96.8 ± 11.0) BqKg^{-1} respectively in Ofiki; and, 1.4 – 2.2 (mean: 1.9 ± 0.7), 1.1 - 3.0 (mean: 1.9 ± 0.5) and, 48.2 – 140.1 (mean: 99.7 ± 6.2) BqKg^{-1} in Igbeti.

Furthermore, the average concentrations of ^{226}Ra, ^{228}Ra and ^{40}K recorded in food crops(yam, cassava and maize) ranged from 3.2 – 6.0 (mean: 3.7 ± 0.9), 1.8 – 3.0 (mean: 2.5 ± 0.7) and, 84.6 – 160.4 (mean: 128.5 ± 7.2) BqKg^{-1} respectively in Iwere-Ile; 2.9 – 7.0 (mean: 5.6 ± 1.1), 1.4 – 3.1 (mean: 2.4 ± 1.6) and, 120.8 – 170.4 (143.8 ± 5.6) BqKg^{-1} respectively in Komu; 3.8 – 6.2 (mean: 4.7 ± 1.6), 1.4 – 2.3 (mean: 1.8 ± 0.7) and, 80.6 – 172.6 (mean: 139.2 ± 13.2) BqKg^{-1} respectively in Ofiki; and, 4.0 – 9.8 (6.6 ± 1.4), 1.4 – 2.8 (mean: 2.3 ± 0.9) and, 100.3 – 180.2 (mean: 147.0 ± 14.2) BqKg^{-1} respectively in Igbeti. The average soil-to-vegetables transfer factors for ^{226}Ra, ^{228}Ra and ^{40}K ranged from: 0.070 – 0.210 (mean: 0.123), 0.040 – 0.080 (mean: 0.058) and, 0.150 – 0.250 (mean: 0.215) in Iwere-Ile; 0.050 – 0.080 (mean: 0.065), 0.030 – 0.060 (mean: 0.040) and, 0.080 – 0.280 (mean: 0.185) in Komu; 0.060 - 0.120 (mean: 0.093), 0.030 – 0.040 (mean: 0.036) and, 0.110 – 0.450 (mean: 0.243) in Ofiki; and, 0.060 – 0.100 (mean: 0.080), 0.030 – 0.080 (mean: 0.050) and, 0.040 – 0.340 (mean: 0.265) in Igbeti; while the average soil-to-food crops transfer factors for ^{226}Ra, ^{228}Ra and ^{40}K ranged from 0.130 – 0.210 (mean: 0.177), 0.090 – 0.140 (mean: 0.110) and, 0.200 – 0.540 (mean: 0.377) respectively in Iwere-Ile; 0.140 – 0.260 (mean: 0.210), 0.040 – 0.080 (mean: 0.060) and, 0.310 – 0.410 (mean: 0.356) respectively in Komu; 0.090 – 0.200 (mean: 0.150), 0.030 – 0.060 (mean: 0.050) and, 0.210 – 0.470 (mean: 0.370) respectively in Ofiki; and, 0.140 – 0.320 (mean: 0.210), 0.050 – 0.060 (mean: 0.056) and, 0.280 – 0.430 (mean: 0.363) respectively in Igbeti.

Adesiji and Ademola, (2019) examined the soil-to-maize transfer factor of natural radionuclides in a tropical ecosystem of Nigeria in virgin soil and tailings from an abandoned tin mining site in Jos using NaI(Tl) gamma detector. Three different groups of soil for planting were prepared by the researchers from the tailings and the virgin soil. Group A consists of soil sample from the virgin land only, group B was made up of soil sample from the tailings only while group C consists of equal ratio by dry mass of soil samples from tailings and virgin land. The activity concentrations (mean ±STD) of ^{40}K, ^{238}U and ^{232}Th in the three different soil samples used for this study were: 374.01 ± 590.51, 242.13 ± 429.10, and 1776.08 ±4164.89 BqKg^{-1} respectively in Group A; 5008.18 ± 2427.16, 2354.98 ± 1260.39, and 26211.90 ± 7178.22 BqKg^{-1} (Group B); and, 1573.93 ± 3123.65, 2763.90 ± 2345.77, and 15294.77 ± 6924.46 BqKg^{-1} respectively for group C.

The activity concentrations (mean ± STD) of ^{40}K, ^{238}U and ^{232}Th recorded in different maize plant components (seed, stem, leaf and root) grown in three soil groups were: 105.43 ± 37.21, BDL, and 318.46 ± 499.96 BqKg^{-1} respectively for seed; 685.08 ± 245.70, BDL, and 828.87 ±783.01 BqKg^{-1} (Stem); 371.13 ± 137.34, 80.06 ± 5.60 and 304.31 ± 221.50 Bq.kg^{-1} (Leaf) and for root, 561.34 ± 372.74, 245.47 ± 322.23, 1065.80 ± 1035.16 BqKg^{-1} respectively in Group A, and for Group B, 127.04 ± 115.46, 25.58 ± 23.08 and 1098.08 ± 854.13 BqKg^{-1} respectively for ^{40}K, ^{238}U and ^{232}Th (Seed); 299.90 ± 198.23, BDL, and 458.51 ± 276. 73 BqKg^{-1} (Stem); 190.83 ± 165.21, BDL, and 826.37 ± 1182 .03 BqKg^{-1} (Leaf); and 243.77 ± 252.77, 367.19 ± 442.38, and 3831.23 ± 2282.00 BqKg^{-1} (Root); while for maize plant grown on Group C soil samples, 283.50 ± 325.77, BDL, and 433.72 ± 671.35 BqKg^{-1}were recorded for ^{40}K, ^{238}U and ^{232}Th in Seed; 328.59 ± 185.61, BDL, and 184.49 ± 81.32 BqKg^{-1} (Stem); 349.48 ± 477.59, 18.08 ± 9.53, and 238.05 ± 64.64 BqKg^{-1} in Leaf, and 298.94 ± 504.20, 185.36 ± 120.82, and 1648.80 ± 913.12 BqKg^{-1} respectively in root. The geometric mean (GM) of the transfer factor values, from the findings of the study, for ^{40}K, ^{238}U and ^{232}Th ranged from 0.02 – 0.29, BDL – 0.008, and 0.01 – 0.09 respectively in the seeds; 0.04 – 1.74, BDL, and 0.01 – 0.29 respectively in the stems; 0.03 – 0.93, BDL – 0.33, and 0.02 – 0.08 in the leaves; and 0.03 – 1.29, 0.05 – 0.38, and 0.08 – 0.41 in the roots.

The focus of research conducted by Azionu *et. al.*, (2021) was on the radiological health hazard indices, natural radioactivity assessment and soil-to-plant transfer factors in some selected locations used for storage of discarded (used) crude oil (production) pipes in Niger Delta region of Nigeria: Eket Mobil Terminal (MOBIL), Akwa Ibom State; Ogbodu Village (OGB), and Port Harcourt Steel Village (PSV) in Rivers State. Gamma ray spectrometer with NaI(Tl) detector was adopted for the analysis of samples in the study. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil samples ranged from 59.88 – 230.43 (mean: 109.47 ± 5.14), 8.34 – 20.69 (mean: 15.96 ± 5.31) and, BDL – 26.48 (mean: 14.35 ± 4.35) BqKg^{-1} respectively in MOBIL; 123.96 – 416.57 (mean: 210.93 ± 1.85), BDL – 11.04 (mean: 9.50 ± 2.04) and, BDL – 16.88 (mean: 14.62 ± 0.77) BqKg^{-1} respectively in OGD; and 25.33 – 60.88 (mean: 38.27 ± 4.01), 7.18 – 19.14 (mean: 13.64 ± 4.92) and, BDL – 11.69 (mean: 10.76 ± 4.92) BqKg^{-1} respectively PSV. The average of ^{40}K, ^{226}Ra and ^{232}Th in all the soil samples from all the locations in the study were: 119.56, 13.03 and 13.24 BqKg^{-1} which is less than the world average of 400, 35 and 30 BqKg^{-1} (UNSCEAR, 2000) respectively. The soil radiation hazard indices computed from the study for Radium equivalent (Ra_{eq}), gamma index (I_y), external and internal hazard indices (H_{ex} and H_{in}), absorbed dose of radiation (D), annual effective dose equivalent (AEDE), annual gonadal equivalent dose (Gonadal), excess lifetime cancer risk (ELCR) and activity utilization index (AUI) were: 147.70 BqKg^{-1}, 0.30 mSv.y^{-1}, 0.11 mSv.y^{-1}, 0.15 mSv.y^{-1}, 19.23 nGy.h^{-1}, 0.02 mSv.y^{-1}, 0.13 μSv.y^{-1}, 0.06 and 0.38 mSv.y^{-1} respectively. All the mean values obtained in the study are within their International permissible standards/limits (UNSCEAR, 2000; 2008).

The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th recorded in plant samples were: 317.50 ± 5.44, BDL, and 6.49 ±3.40 BqKg^{-1} (Banana); 90.76 ± 6.08, BDL, and 10.09 ± 3.45 BqKg^{-1} (Maize); and 376.92 ± 5.43 BqKg^{-1}, BDL and BDL (Grass) in MOBIL; 408.20 ± 5.04, BDL, and 4.09 ± 2.97 BqKg^{-1} (Banana); 276.17 ± 4.40, BDL, and 16.08 ± 2.83 BqKg^{-1} (Maize); and 160.33 ± 5.55, BDL, and BDL (Grass) in OGD; and, 452.05 ± 3.85, BDL, and 7.69 ± 3.25 BqKg^{-1} (Banana); 371. 93 ± 5.60, BDL, and 5.29 ± 4.18 BqKg^{-1} (Maize) and 130.10 ± 7.49, BDL, and BDL (Grass) in PSV. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in all the plants samples in the study areas were: 302.48 ± 153.89, BDL, and 7.69 ± 4.27 BqKg^{-1} respectively, while the mean soil-to-plant transfer factor of ^{40}K, ^{226}Ra and ^{232}Th in MOBIL were 3.56, BDL and 1.23 respectively; 1.81, BDL, and 0.95 respectively in OGD; and 10.83, BDL, and 0.46 in PSV. From the results of the study, the highest transfer factor was recorded in Banana grown in Port Harcourt Steel Village (PSV) in Rivers State.

Adeleke *et. al*., (2021), estimated soil-to-plant transfer factors of natural, ^{238}U, ^{232}Th, ^{40}K and artificial radionuclides, ^{137}Cs in some selected medicinal plants (Moringa leaves, Goat weed, Ginger and Turmeric) in Minna and Maikunkele (Niger State); and Mando and Kachia (Kaduna State) using Gamma ray spectrometer with High Purity Germanium (HPGe) detector. The activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs of soil samples in the study areas ranged from 9.51 – 58.98, 17.85 – 96.92, 309.84 – 810.16 and BDL – 0.062 BqKg^{-1} respectively, while in the medicinal plants used in the study, the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs ranged from: 1.34 – 7.08, 5.30 – 13.75, 75.82 – 122.74 BqKg^{-1} and BDL respectively (Moringa); 2.41 – 10.37, 7.68 – 13.61, 45.16 – 206.34 BqKg^{-1} and BDL respectively (Goat weed); 3.36 – 5.23, 6.11 – 7.24, 25.93 – 239.72 BqKg^{-1} and BDL respectively (Ginger); and 1.73 – 2.46, 5.22 – 7.91, 11.70 – 33.53 BqKg^{-1} and BDL respectively in Turmeric. The transfer factors of ^{238}U, ^{232}Th and ^{40}K in the medicinal plants, obtained in the study, ranged from 0.033 – 1.090, 0.067 – 0.762 and 0.024 – 0.774 with the mean transfer factor 0.303, 0.226 and 0.227 respectively. The estimated adsorbed dose rate (D) from the study ranged between 46.66 nGy.h^{-1} and 129.20 nGy.h^{-1}, with the mean value of 81.90 nGy.h^{-1}. The mean absorbed dose rate (D), obtained in the study is higher than the world average value of 59.00 nGy.h^{-1} (Patra *et. al*., 2008; Agbalagba *et. al*., 2016) however, it is equally lower than the recommended safe limit of 84 nGy.h^{-1} for outdoor exposure (UNSCEAR, 2008; Ononugbo *et. al*., 2016).

The annual effective dose equivalent (AEDE) for outdoor exposure ranged between 0.0358 and 0.129 mSv.y^{-1} with a mean value of 0.0824 mSv.y^{-1} while for indoor exposure, it ranged between 0.1432 and 0.5120 mSv.y^{-1} with an average of 0.3298 mSv.y^{-1}for indoor exposure. The mean value AEDE for outdoor exposure obtained in this study is higher than the world average value of 0.07 mSv.y^{-1} but within the safety limit of UNSCEAR and ICRP recommended and permissible limits of 1.00 mSv.y^{-1} for general public (UNSCEAR, 2008; IAEA, 2006). The average annual committed effective dose (AACED) values due to ingestion of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in Moringa leaves, Goat weed, Ginger and Turmeric were estimated, and it ranged between 0.0107 and 0.0542 mSv.y^{-1} with a mean value of 0.0126 mSv.y^{-1} with the assumption that the consumption rate per year is 1 Kg (Zakaly *et. al*., 2019; Badawy *et. al*., 2018, and Awad *et. al*., 2020). The average value of AACED obtained in the study is lower the world average value of 0.3 mSv.y^{-1} reported in literature (UNSCEAR, 2008).

Tyovenda *et. al*., (2022) investigated the radiological risk of farmlands and soil-to-crop transfer factors of natural radioactivity in Jalingo and Wukari Local Government Areas of Taraba State, Nigeria. Gamma ray spectrometer coupled with HPGe detector was used to analyse the activity concentrations of ^{40}K, ^{232}Th and ^{238}U in soil samples and edible parts of crop samples (maize, beans, yam and cassava tubers) grown on farmlands in the two selected Local Government Areas. The activity concentrations of ^{40}K, ^{232}Th and ^{238}U in soil samples in Wukari ranged from 100.70 – 340.24, 58.99 – 157.12 and 8.06 – 47.35 $BqKg^{-1}$, with an average of 199.21 ± 42.95, 87.23 ± 18.64 and 25.37 ± 8.71 $BqKg^{-1}$ respectively while in Jalingo, it ranged from 332.17 – 1252.05, 85.56 – 259.09, and 20.20 – 127.60 $BqKg^{-1}$ with an average of 633.13 ±160.72, 141.14 ±31.14 and 71.20 ±20.95 $BqKg^{-1}$. The activity concentrations of ^{40}K, ^{232}Th and ^{238}U in soil samples in Jalingo (633.13, 141.14 and 71.20 $BqKg^{-1}$) were found to be higher than the world average values of 400, 30 and 35 $BqKg^{-1}$ respectively (UNSCEAR, 2000). Also, the activity concentrations of ^{40}K, ^{232}Th and ^{238}U in edible parts of crops harvested from these farms ranged from 110.46 – 550.30, 8.35 – 16.30 and 7.04 – 20.16 $BqKg^{-1}$ with a mean of 306.17 ± 83.86, 12.67 ± 1.50 and 11.51 ± 2.33 $BqKg^{-1}$ respectively in Jalingo, while in Wukari it ranged from 19.09 – 198.27, 26.88 – 95.32 and 8.20 - 17.40 $BqKg^{-1}$, with a mean of 82.77 ± 31.12, 49.75 ± 12.02 and 11.00 ± 1.74 $BqKg^{-1}$ respectively. The transfer factors of ^{40}K, ^{232}Th and ^{238}U from soil-to-crop in Jalingo ranged from 0.245 – 1.000, 0.098 – 0.166 and 0.064 – 0.597 with an average of 0.509 ± 0.130, 0.104 ± 0.020 and 0.270 ± 0.100 respectively, and in Wukari it ranged from 0.161 – 0.611, 0.414 – 0.686 and 0.191 – 1.649 with a mean of 0.395 ± 0.100, 0.566 ± 0.050 and 0.743 ± 0.270 respectively. The radiological hazard indices: absorbed dose rate, D; annual effective dose rate, AEDE: radium equivalent, Ra_{eq}; external and internal hazard indices, H_{ext} and H_{in}; and expected lifetime cancer risk, ELCR; of the soil samples recorded in the study were: 169.685 $nGy.h^{-1}$; 0.208 $mSv.y^{-1}$; 375.506 $BqKg^{-1}$; 1.014; 1.293 and 7.287×10^{-4} respectively in Jalingo and 84. 059 $nGy.h^{-1}$; 0.103 $mSv.y^{-1}$; 191.235 $BqKg^{-1}$; 0.517, 0.642 and 3.610×10^{-4} respectively in Wukari Local Government area of Taraba State, Nigeria.

RESRAD (Computer) Model was used in the study to forecast what the value of absorbed dose will be in the Local Government Areas in the next 60 years, and 2.519 $mSv.y^{-1}$ was obtained for farmlands in Jalingo while 3.430 $mSv.y^{-1}$ was recorded for Wukari farms. Also, the corresponding maximum cancer risk for all the pathways evaluated was 5.465×10^{-3} for the next 32 years and 4.7×10^{-3} in the next 51 years respectively. The absorbed dose rate and AEDE for the two locations were above the safety limit of 59.0 $nGy.h^{-1}$ and 0.07 $mSv.y^{-1}$ recommended by UNSCEAR, 2008. The analysis of the RESRAD model used in the study shows that the water independent pathway is the most significant in the determination of excess cancer risk and caused by radiation from the plant (direct and airborne), followed by soil (direct and airborne) and then inhalation.

Ocheje *et. al.*, (2021) also explored the transfer factor and dose rate of naturally occurring radionuclide materials in some selected crops (yam, maize, beans and cassava) in four (4) Local Government Areas (Lafia, Keffi, Nassarawa Eggon and Doma) in Nassarawa State, Nigeria, using High Purity Germanium, HPGe, detector. The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples in study areas were: 24.80, 16.75 and 309.40 $BqKg^{-1}$ respectively in Lafia; 26.82, 22.12 and 569.33 $BqKg^{-1}$ in Keffi; 22.91, 27.82 and 389.71 $BqKg^{-1}$ in Nassarawa eggon (N/eggon); and, 48.30, 29.63 and 366.34 $BqKg^{-1}$ in Doma respectively. The mean values of ^{238}U, ^{232}Th and ^{40}K recorded in all the soil samples in Nassarawa were: 30.71, 24.08 and 408.69 $BqKg^{-1}$ respectively. However, the mean activity concentration of ^{40}K recorded in soil samples in Nassarawa State is slightly greater than that of the world average of 400 $BqKg^{-1}$. Also, the average concentrations of ^{238}U, ^{232}Th and ^{40}K in crop samples obtained in the study were: 16.78, 8.67 and 142.64 $BqKg^{-1}$ respectively in Lafia; 17.28, 16.67 and 221.14 $BqKg^{-1}$ respectively in Keffi; 18.05. 17.08 and 126.96 $BqKg^{-1}$ respectively in N/Eggon; and, 17.70, 19.6, and 141.80 $BqKg^{-1}$ respectively in Doma while the mean concentration in all the crop samples for each of the natural radionuclides were 17.45, 15.51 and 158. 14 $BqKg^{-1}$ respectively. The average soil-to crop transfer factor of ^{238}U, ^{232}Th and ^{40}K, in Lafia, were: 0.740, 0.482 and 0.329 respectively; Keffi: 0.644, 0.754 and 0.388 respectively; N/Eggon: 0.453, 0.363 and 0.335 respectively; and, Doma: 0.366, 0.369 and 0.054 respectively. The regression analyses carried out on the activity concentrations of radionuclides in soil and plants show a non-linear relationship between the parameters of interest. This is in agreement with the earlier research studies and this may be due to the fact that the uptake of elements by plants can be influenced by various factors like soil moisture, cation exchange capability, pH value, the organic matter content, soil nutrient and clay content of the soil (Simon *et. al*., 2002).

The estimated values of radiological hazard indices: D (absorbed dose); AEDE (Annual effective dose rate), Ra_{eq}., (Radium equivalent); H_{ext}., (External hazard index); H_{in}., (Internal hazard index); and ECLR (Excess lifetime cancer risk) in the study were: 40.064 $nGy.h^{-1}$, 0.049 $mSv.y^{-1}$, 81.769 $BqKg^{-1}$, 0.221, 0.282 and 0.172 x 10^{-3} respectively in Lafia; 50.3445 $nGy.h^{-1}$, 0.062 $mSv.y^{-1}$, 102.286 $BqKg^{-1}$, 0.276, 0.349 and 0.216 x 10^{-3} in Keffi; 63.138 $nGy.h^{-1}$, 0.077 $mSv.y^{-1}$. 159.091 $BqKg^{-1}$, 0.430, 0.526 and 0.27 x 10^{-3} in Nassarawa Eggon; and, 269.974 $nGy.h^{-1}$, 0.331 $mSv.y^{-1}$, 118.871 $BqKg^{-1}$, 0.321, 0.452 and 1.159 x 10^{-3} respectively in Doma. The mean of estimated values of D, AEDE, Ra_{eq}., H_{ext}., H_{in}., and ECLR in all the study areas in Nassarawa State were: 105.880 $nGy.h^{-1}$, 0.130 $mSv.y^{-1}$, 115.504 $BqKg^{-1}$, 0.312, 0.402 and 0.455 x 10^{-1} respectively. The values of Ra_{eq} activity ranged from 81.77 to 159.09 $BqKg^{-1}$ with an average of 115.50 $BqKg^{-1}$ which is lower than the recommended safety limit value of 370 $BqKg^{-1}$ (UNSCEAR, 2000). The External and Internal hazard indices H_{ext}. and H_{in}., are less than Unity which implies that the activity concentrations of natural radionuclides in the soil in Nassarawa is within the recommended environmental safety limit. The gamma absorbed dose rate (air) in the study areas ranged from 40.06 to 269.97 $nGy.h^{-1}$ with a mean value of 105.88 $nGy.h^{-1}$, this is higher than the world average value of 54 $nGy.h^{-1}$ (UNSCEAR, 2008) while mean value of outdoor annual effective dose equivalent, AEDE, obtained in the study, 0.129 $mSv.y^{-1}$, is higher than the world average value and maximum limit 0f 0.10 $mSv.y^{-1}$ recommended by the World Health Organization (WHO, 2006). However, it is lower than 1$mSv.y^{-1}$ safety limit recommended by NCRP (NCRP, 1975) and ICRP (ICRP, 1990). The higher values of AEDE reported in some areas of study could be as a result of high agricultural activities and the use of soil enhancement chemical fertilizers and herbicides for weeding and pest control purposes. Furthermore. The mean ECLR value obtained from the study, 0.46 x 10^{-3}, is higher than the world's average of 0.299 x 10^{-3} (UNSCEAR, 1988), indicating that there is a tendency of higher cancer risk in the study area due to exposure to radiation from primordial radionuclides in the area.

Avwiri *et. al*., (2021) probed the radionuclide transfer factors of ^{226}Ra, ^{232}Th and ^{40}K in staple foods and its antecedent health risks to consumers in Niger Delta region of Nigeria. The Niger Delta region of Nigeria is made up of nine States which include: Ondo, Edo, Rivers, Delta, Cross River, Imo, Bayelsa, Abia and Akwa Ibom. Each of the popular food crops grown in each of the states: Groundnut (Ilaje/Ondo), Beans (Ohosu/Edo), Maize (Emohua/Rivers), Rice (Ughelli/Delta), Potatoes (Obio-Akpor/Rivers), Banana (Odukpani/Cross River), Cassava (Adagbabiri/Bayelsa), Yam (Aba/Abia), Plantain (Eket/Akwa Ibom) and Cocoyam (Obinnze/Imo) as well as their corresponding soil samples were analysed in the study using gamma ray spectrometry with NaI(Tl) detector. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples in Niger Delta region ranged from 7.49 ± 2.33 to 19.88 ± 3.24, 4.88 ± 4.12 to 289.00 ± 4.48 and 80.79 ± 3.89 to 222.01 ± 3.66 $BqKg^{-1}$ respectively. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in all the soil samples were; 14.97 ±2.91, 48.53 ± 3.16 and 164.42 ± 3.83 $BqKg^{-1}$, apart from ^{232}Th whose activity concentration is greater than the safety limit value of 30 $BqKg^{-1}$, others (^{226}Ra, and ^{40}K) have their concentrations lower than 35 and 400 $BqKg^{-1}$ recommended by UNSCEAR, 2008.

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in food crop samples in the study area (Niger Delta region) also ranged from 12.39 ± 5.55 (cocoyam) to 82.96 ± 4.03 (yam), 17.53 ± 5.17 (yam) to 28.86 ± 5.79 (cassava), and 53.69 ± 5.37 (plantain) to 214.69 ± 4.36 $BqKg^{-1}$ (banana) respectively. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in all the crop samples were: 38.44 ± 4.52, 22.85 ± 5.59 and 96.17 ± 5.04 $BqKg^{-1}$ respectively. The soil-to-crop transfer factors of ^{226}Ra, ^{232}Th and ^{40}K in the study area ranged from 0.65 – 6.09, 0.10 – 4.75 and 0.28 – 2.06 respectively. The soil-to-crop transfer factor values estimated in the study is higher than values recommended by the International Atomic Energy Agency, (IAEA, 1993) for ^{226}Ra and ^{232}Th (in roots, vegetables, fruits and grains for human consumption) which are: 4.9 x 10^{-3} and 2.1 x 10^{-4} respectively, and 3.0 x 10^{-1} recommended for ^{40}K by (NCRP, 1991). This was attributed to geological factors and agricultural practices employed in these areas. The values of Ra_{eq} activity of the soil in the study areas ranged from 27.40 – 230.02 $BqKg^{-1}$ which falls below the recommended value of 370 $BqKg^{-1}$ (UNSCEAR, 2000). The estimated values of gamma absorbed dose rates of the soil in the region varied from 12.84 (Rivers) to 196.06 $nGy.h^{-1}$ (Cross River) and the corresponding annual effective dose equivalent ranged from 0.016 (Rivers) to 0.240 $mSv.y^{-1}$ (Cross River). These values are within the normal world's averages (UNSCEAR, 2000).

The annual effective dose, as a result of consumption of all the food crops, was determined for adults with emphasis on ingestion of ^{226}Ra and ^{232}Th only. This is because potassium is an important element require by human body and its absorption is under homeostatic control. The annual effective dose values ranged from 26.82 (Rice) to 283.39 $\mu Sv.y^{-1}$ (Banana). The dose values obtained for banana, yam, cassava and plantain are higher than the recommended reference level of 70 $\mu Sv.y^{-1}$ (Okeme *et. al.*, 2016). This implies that the consumption of these crops for a period of time may lead to significant radiation health risk for consumers. Fatal and non-fatal cancer risk were also evaluated in the study, the results of the fatal cancer risk to adult consumer per year of each crop sample ranged from 1.47 x 10^{-6} (Rice) to 15.58 x 10^{-6} (Banana) and the associated lifetime fatality cancer risk varied from 1.03 x 10^{-4} (Rice) to 10.91 x 10^{-4} (Banana). The cancer fatality risk value(s) obtained from the study is within the negligible cancer fatality risk value recommended by U.S. EPA (2008), which is in the range of 1.0 x 10^{-6} to 1.0 x 10^{-4}. The lifetime hereditary effect to adult per year varied from 0.536 x 10^{-7} (Rice) to 5.67 x 10^{-7} (Banana) with the associated lifetime hereditary effect in adult in the range of 3.75 x 10^{-6} (Rice) to 39.67 x 10^{-6} (Banana).

Alausa *et. al.*, (2020) assessed the radiological impact of farm soils on Ofada rice in three major Ofada rice producing areas: Ekiti (Aramoko), Ebonyi (Abakaliki) and Ogun (Ofada) States, Nigeria using gamma ray spectrometer and NaI(Tl) gamma ray detector. The results of the study shows that the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in farm soil in the study areas ranged from 243.7 – 450.5, 9.0 – 12.9 and 8.8 – 11.2 $BqKg^{-1}$ respectively in Ofada (Ogun State); 238.5 - 350.1, 8.9 – 11.9 and 6.2 – 13.0 $BqKg^{-1}$ respectively in Abakaliki (Ebonyi State); and, 265.3 – 420.5, 8.7 – 12.2 and 8.3 – 10.7 $BqKg^{-1}$ in Aramoko (Ekiti State). The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th obtained for soil samples in the study were: 333.9 ± 56.0, 11.1 ± 1.0, and 9.9 ± 0.9 $BqKg^{-1}$ respectively (Ofada); 306.9 ± 30.7, 10.7 ± 0.9, and 9.4 ± 1.4 $BqKg^{-1}$ respectively (Abakaliki); and 321.8 ± 43.7, 10.8 ± 0.9 and 9.5 ± 0.7 $BqKg^{-1}$ respectively in Aramoko. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th, of the soil, obtained in all the study areas were less than the world average values (400.0, 35.0 and 30.0 $BqKg^{-1}$) reported by UNSCEAR, (2008).

Also, the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in rice samples in the study areas ranged from: 201.1 – 330.5 (mean: 261.8 ± 37.9), 8.2 – 11.3 (mean: 9.6 ± 1.0), and 7.2 – 10.2 (mean: 8.7 ± 0.9) $BqKg^{-1}$ respectively in Ofada farms; 208.5 – 321.5 (mean: 257.2 ± 35.5), 7.5 – 11.8 (mean: 9.3 ± 0.9) and 5.0 – 10.3 (mean: 7.8 ± 1.5) $BqKg^{-1}$ respectively in Abakaliki; and, 201.3 – 340.1 (mean: 248.2 ± 40.1), 6.8 – 11.2 (mean: 9.2 ± 1.1) and 5.6 – 8.9 (mean: 7.6 ± 0.8) $BqKg^{-1}$ in Aramoko, Ekiti State. The mean of estimated values of soil-to-plant transfer factors of ^{40}K, ^{226}Ra and ^{232}Th in rice of the study areas were: 0.784, 0.865 and 0.879 in Ofada farms; 0.838, 0.869 and 0.830 in Abaliki farms; and 0.771, 0.852 and 0.800 in Aramoko farms. The mean absorbed gamma dose rates in the farm soils in Ofada, Abakaliki and Aramoko were: 25.6, 24.0 and 24.8 $nGy.h^{-1}$. These recorded values were lower than world average value of 59.0 $nGy.h^{-1}$ (UNSCEAR, 2000). While the effective dose rate from the farm soil were: 0.032 ± 0.003 $mSv.y^{-1}$ in Ofada, 0.029 ± 0.002 $mSv.y^{-1}$ in Abakaliki, and 0.030 ± 0.002 $mSv.y^{-1}$ in Aramako, each of these values is equally lower in magnitude than the world average value of 0.30 $mSv.y^{-1}$.

The mean Radium equivalent activity, Ra_{eq} of the farm soils in Ofada, Abakaliki and Aramoko: 50.95 ± 4.87, 47.54 ± 2.86 and 49.20 ± 3.51 $BqKg^{-1}$ were lower than the safety limit value of 370 $Bq.Kg^{-1}$ (Jibri *et. al.*, 2009). Also, the mean values of internal hazard index, external hazard index and the gamma index of the farm soils in each of the study areas: 0.17 ± 0.01, 0.14 ± 0.01, and 0.20 ± 0.02 (Ofada); 0.16 ± 0.01, 0.13 ± 0.01, and 0.18 ± 0.01 (Abakaliki); and, 0.16 ± 0.01, 0.13 ± 0.01 and 0.19 ± 0.01 (Aramoko) respectively were less than unity, which is the recommended environmental safety limit (Jibri *et. al.*, 2009). The mean effective dose rates obtained in the study for Ofada, Abakaliki and Aramoko were: 105.60 ± 8.2, 98.10 ± 10.2 and 96.2 ± 8.5 $\mu Sv.y^{-1}$ and the average cancer risk due to ingestion/consumption of rice in these communities were: 0.32 x 10^{-3} (Ofada), 0.31 x 10^{-3} (Abakaliki) and 0.30 x 10^{-3} (Aramoko).

Alausa, (2020) carried out a radiometric assessment of farm soils and food crops (Guinea corn, Maize, Yam and Cassava) grown in Kuru-Jos, Nigeria, by the use of gamma ray spectrometry with Thalium-activated sodium-iodide [NaI(Tl)] detector. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in farmlands used for cultivation of Guinea corn were: 989.9 ± 279.9, 144.4 ± 59.9 and 205.4 ± 124.4 $BqKg^{-1}$ respectively; 660.9 ± 372.6, 105.1 ± 24.8 and 197.8 ± 65.7 $BqKg^{-1}$ respectively in soils used for maize cultivation; 1,261.0 ± 481.4, 167.5 ± 37.6 and 193.7 ± 65.7 $BqKg^{-1}$ respectively in soils used for cultivation of yam; and, 1105.6 ± 357.7, 119.4 ± 59.0 and 192.2 ± 50.7 $BqKg^{-1}$ respectively in farm soils used for cultivation of cassava. The average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in food crops recorded in the study were: 351.0 ± 123.9, 38.0 ± 9.7 and 29.9 ± 18.3 $BqKg^{-1}$ in Guinea corn; 126.3 ± 83.3, 26.9 ± 17.1 and 31.6 ± 23.9 $BqKg^{-1}$ respectively in maize; 456.2 ± 126.0, 46.9 ± 9.6 and 29.5 ± 12.8 $BqKg^{-1}$ respectively in yam; and, 300.7 ± 55.7, 33.3 ± 5.4 and 24.6 ± 2.4 $BqKg^{-1}$ respectively in cassava.

The estimated values of soil-to-food crop transfer factors of ^{40}K, ^{226}Ra and ^{232}Th in the study, ranged from 0.12 – 0.59 (mean: 0.37 ± 0.13), 0.10 – 0.87 (mean: 0.31 ± 0.19) and 0.02 – 0.65 (mean: 0.19 ± 0.17) respectively in Guinea corn; 0.02 – 0.53 (mean: 0.23 ± 0.10), 0.03 – 0.60 (mean: 0.27 ± 0.17) and 0.01 – 0.39 (mean: 0.17 ± 0.13) respectively in Maize; 0.20 – 0.52 (mean: 0.39 ± 0.13), 0.19 – 0.40 (mean: 0.29 ± 0.08) and 0.08 – 0.23 (mean: 0.16 ± 0.05) respectively in Yam; and, 0.15 – 0.44 (mean: 0.29 ± 0.09), 0.15 – 0.47 (mean: 0.33 ± 0.13) and

0.10 – 0.16 (mean: 0.13 ± 0.02). The mean gamma absorbed dose, outdoor effective dose, ingestion dose and excess lifetime cancer risk obtained in the study for Guinea corn were: 240.2 ± 94.8 $nGy.h^{-1}$, 0.29 ± 0.12 $mSv.y^{-1}$, 329.3 ± 136.7 $\mu Sv.y^{-1}$ and (0.9 ± 0.2) x 10^{-3} respectively; for Maize: 204.2 ± 31.6 $nGy.h^{-1}$, 0.25 ± 0.04 $mSv.y^{-1}$, 304.1 ± 179.1 $\mu Sv.y^{-1}$ and (0.6 ± 0.3) x 10^{-3} respectively; while 253.9 ± 64.0 $nGy.h^{-1}$, 0.31 ± 0.08 $mSv.y^{-1}$, 1231.9 ± 362.8 $\mu Sv.y^{-1}$ and (3.8 ± 0.7) x 10^{-3} respectively, were estimated for yam; and, 225.8 ± 61.1 $nGy.h^{-1}$, 0.28 ± 0.07 $mSv.y^{-1}$, 1072.6 ± 96.0 $\mu Sv.y^{-1}$ and (3.0 ± 0.4) x 10^{-3} respectively obtained for cassava. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th obtained in the all farm soils used for the study were generally higher than the world average values (400.0, 35.0 and 30.0 $BqKg^{-1}$) reported by UNSCEAR, (2008). This was attributed to the dispersal of tin tailings all over the farmlands due to continuous illegal mining in the study area. The mean transfer factors recorded for ^{226}Ra and ^{232}Th in all the food crops were equally higher than the recommended values of 4.9 x10^{-3} and 2.1 x 10^{-4} respectively (IAEA, 1993). However, for ^{40}K, values lower than the recommended limit, 3 x 10^{-1} (NCRP, 1991) were obtained in Maize and Cassava while higher values are recorded in Guinea corn and Yam. This is due to variation in characteristics of food crops, in one part, and level of concentration of radionuclides in the soil, on the other part. The gamma absorbed dose obtained for all the farm soils in the study is greater than both the world average value of 59.0 $nGy.h^{-1}$ and the recommended safety limit of 84.0 $nGy.h^{-1}$ (UNSCEAR, 2008). The values of annual ingestion effective doses exhibited by the crops are higher than the world average value of 70 $\mu Sv.y^{-1}$ while the excess lifetime cancer risks were also higher than that of the world average limit of 1.0 x 10^{-3}.

Essien *et. al.*, (2021) determined the activity concentrations and soil-to-plant transfer factors of natural radionuclides in Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria using gamma spectrometry analytical method with [NaI(Tl)] scintillation detector. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soils in Ufam ranged from: BDL – 149.46 (mean: 99.11 ± 7.12), BDL – 16.25 (mean: 3.60 ± 0.99) and 4.11 – 12.71 (mean: 8.64 ± 0.84) $BqKg^{-1}$ respectively; and in Obot Nduo farm soils: BDL – 153.46 (mean: 93.60 ± 6.72), BDL – 31.22 (mean: 8.96 ± 2.13) and 1.03 – 8.72 (mean: 6.12 ± 0.60) $BqKg^{-1}$ respectively. The specific activity of ^{40}K, ^{238}U and ^{232}Th in cassava crops in Ufam ranged from: 119.86 – 538.73 (mean: 360.40 ± 25.63), BDL – 26.30 (mean: 6.56 ±1.65) and, BDL – 15.89 (mean: 6.21 ± 0.61) $BqKg^{-1}$ respectively while for cassava crops in Obot Udua farms, it ranged from: 289.54 – 601.28 (mean: 391.13 ± 28.07), 1.54 – 32.14 (mean: 11.64 ± 2.94) and BDL – 7.88 (mean: 3.09 ± 0.30) $Bq.Kg^{-1}$ respectively.

The mean value of soil-to-cassava transfer factor of ^{40}K, ^{238}U and ^{232}Th estimated in the study were: 3.64, 1.82 and 0.72 respectively in Ufam; and 4.18, 1.30 and 0.51 respectively in Obot Ndua. These values are higher than the recommended value of 3 x 10^{-1} for ^{40}K (NCRP, 1991), 4.9 x 10^{-3} for ^{238}U and 2.1 x 10^{-4} for ^{232}Th respectively (IAEA, 1993). Higher values of activity concentrations of ^{40}K, ^{238}U and ^{232}Th, in the study, were noticed in cassava tubers than the farmlands used for the cultivation of the cassava plant. This may be attributed to farming techniques employed, fertilizers applied and the pesticides used and other human related factors. The effective dose due to consumption of the cassava tuber, with the assumption that the mean annual consumption of cassava in Akwa Ibom State, Nigeria is 127.10 $Kg.y^{-1}$ (for children) and 343.10 $Kg.y^{-1}$ (for adults), ranged from 0.99 – 1.08 $mSv.y^{-1}$ for children and 2.68 – 29.16 $mSv.y^{-1}$ for adult. These values are higher than the recommended annual dose safety limit (reference level) of 70 $\mu Sv.y^{-1}$ (Okeme *et. al.*, 2016).

Jibiri *et. al.*, (2007) investigated the activity concentrations of ^{40}K, ^{226}Ra and ^{228}Th in different food crops (Cereals, Vegetables, Tubers and Legumes) cultivated in Bitsichi, a high background radiation area of Barkin-Ladi Local Government Area in Jos Plateau State, Nigeria using gamma ray spectrometry with NaI(Tl) scintillating detector. The activity concentrations of ^{40}K, ^{226}Ra and ^{228}Th in soil samples from different farms used in the study ranged from: BDL – 166.4 (mean: 96.5 ± 9.6), 10.9 – 470.6 (mean: 216 ± 14.7) and 122.7 – 2189.5 (mean: 734.3 ± 9.3) $BqKg^{-1}$ respectively. While the activity concentrations of ^{40}K, ^{226}Ra and ^{228}Th in the food crop samples ranged from: BDL – 243.2 (mean: 130.6 ± 17.0), BDL – 34.1 (mean: 9.7 ± 4.0) and BDL – 8.1 (mean: 3.1 ± 1.0) $BqKg^{-1}$ respectively in Cereals (grains); 423 7 – 684.5 (mean: 535.9 ± 26.6), 10.7 – 85.5 (mean: 36.2 ± 9.9) and 17.1 – 89.8 (mean: 39.6 ± 8.1) $BqKg^{-1}$ respectively in Tubers; 80.6 – 213.0 (mean: 141.4 ± 21.4), BDL – 32.1 (mean: 12.2 ± 7.3) and BDL – 9.6 (mean: 1.9 ± 0.8) $BqKg^{-1}$ respectively in Vegetables; and, 398.6 – 546.8 (mean: 466.3 ± 19.1), 7.4 – 9.4 (mean: 8.4 ± 3.3) and BDL – 18.9 (mean: 9.7 ± 3.3) $BqKg^{-1}$ respectively in Legumes.

The calculated values of soil-to-edible crop transfer factors of ^{40}K, ^{226}Ra and ^{228}Th in the study were: 1.353, 0.045 and 0.004 respectively in cereals; 5.553, 0.167 and 0.054 respectively in tubers; 1.465, 0.056 and 0.003 respectively in vegetables; and 4.832, 0.039 and 0.013 respectively in legumes. The mean soil-to-crop transfer factor of ^{40}K, ^{226}Ra and ^{228}Th in all the crop samples used in the study were: 3.301, 0.077 and 0.019 respectively, which are all higher the recommended values. The effective ingestion dose of ^{226}Ra and ^{228}Th due to consumption of the crops in the study ranged from 0.18m $Sv.y^{-1}$ (legumes) to 0.74 $mSv.y^{-1}$ (cereals) which is higher than 0.07 $mSv.y^{-1}$ recommended as safety limit value (Okeme *et. al.*, 2016).

Ilori and Alausa, (2019) also estimated the natural radionuclides in grasses, soils and cattle-dungs from a cattle rearing-field at Mangoro-Agege. Lagos State, Nigeria using a well calibrated thallium-doped sodium-iodide scintillating detector. The results obtained from the study show that the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil samples ranged from 301.13 – 440.48 (mean: 403.07 ± 33.85), 10.19 – 13.05 (mean: 11.47 ± 0.75) and 9.12 – 12.08 (mean: 10.44 ± 0.75) $BqKg^{-1}$ respectively; also, the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in grass samples from the study area ranged from 99.57 – 202.41 (mean: 115.46 ± 21.68), 8.44 – 11.21 (mean: 10.06 ±0.75) and 3.00 – 10.50 (mean: 8.31 ± 2.76) $BqKg^{-1}$ respectively; while in cow dung samples, it ranged from 115.21 – 225.44 (mean: 184.90 ± 40.92), 10.13 – 13.17 (mean: 11.50 ± 0.78) and 8.12 – 11.28 (mean: 10.20 ± 0.71) $BqKg^{-1}$ respectively. The activity concentrations of natural radionuclides were higher in cow dung than the corresponding values obtained in the soils in the study area and this was attributed to ingestion of radionuclides from other sources like grazing water, inhalation from atmosphere and the like, by cattle. The values of soil-to-grass transfer factors of ^{40}K, ^{238}U and ^{232}Th estimated in the study ranged 0.24 – 0.32 (mean: 0.29 ± 0.05), 0.73 – 1.09 (mean: 0.88 ± 0.10) and 0.25 – 1.05 (mean: 0.80 ± 0.27) respectively. The mean value of soil-to-grass transfer factor of ^{40}K of 0.29 obtained in the study is lower than 3×10^{-1}, which is the recommended value for ^{40}K (NCRP, 1991). However, the mean values obtained for ^{238}U and ^{232}Th, which are 0.88 and 0.80 respectively are higher than the recommended values of 4.9×10^{-3} and 2.1×10^{-4} (IAEA, 1993).

Table 1 reveals studies and publications on measurement of soil-to-plant transfer factor of natural radioactivity conducted by Scholars in Nigeria, and reviewed in this article at a glance and Table 2 gives the summary of the results of findings obtained by Researchers on the measurements and transfer factors of NORMs in Nigeria.

Table 1: Studies and Publications on transfer factors of NORMs in Nigeria at a glance.

Parameters Estimated	Method of Analysis	Study Samples	Study Area/Location	References
^{40}K, ^{226}Ra, ^{232}Th, Ra_{eq}, H_{ex}, H_{in}, gamma absorbed dose rate D, AEDE, ELCR and Transfer factor	A coaxial type, HPGe detector	Soil and Plant (*Amaranthus hybridus*)	Lagos, Ogun, Ondo, Oyo, Osun and Ekiti States	Ibikunle *et. al*., (2019)
^{40}K, ^{232}Th, ^{238}U, Ra_{eq}, H_{ex}, H_{in}, gamma absorbed dose D, AEDE, AGDE, ELCR and Transfer factor	NaI (Tl) Scintillation detector	Soil and Crop (Cassava)	Delta State (Agbor, Ogwashi-Uku, Ibusa and Igbodo)	Ononugbo *et. al*., (2019)
^{40}K, ^{232}Th, ^{238}U and Transfer factor	NaI (Tl) Scintillation detector	Soil, Vegetables, food crops and Water (borehole, stream and rain)	Osun State (Fashina village)	Oluyide *et. al*., (2018)
^{40}K, ^{226}Ra, ^{232}Th and Transfer factor	NaI (Tl) Scintillation detector	Soil and Crop (rice)	Kogi State (Lokoja and Ibaji)	Okeme *et. al*., (2016)
^{40}K, ^{226}Ra, ^{228}Ra and Transfer factor	NaI (Tl) Scintillation detector	Soil, Vegetables and food crops	Oyo State (Iwere-Ile, Komu, Ofiki and Igbeti)	Ademola, (2022)
^{40}K, ^{232}Th, ^{238}U and Transfer factor	NaI (Tl) Scintillation detector	Soil and maize plant components	Jos. Jos-Plateau State	Adesiji & Ademola, (2019).
^{40}K, ^{226}Ra, ^{238}U, Ra_{eq}, H_{ex}, H_{in}, gamma absorbed dose D, AEDE, AGDE, ELCR, AUI, and Transfer factor	NaI (Tl) Scintillation detector	Soil and Plant	Niger-Delta Region. Akwa Ibom and Rivers State	Azionu *et. al*., (2021)
^{40}K, ^{232}Th, ^{238}U, gamma absorbed dose D, AEDE, AACED and Transfer factor	A coaxial type, HPGe detector	Soil and Medicinal plants	Minna, Niger State and Kaduna, Kaduna State	Adeleke *et. al*., (2021).
^{40}K, ^{232}Th, ^{238}U, Ra_{eq}, H_{ex}, H_{in}, gamma absorbed dose D, AEDE, ELCR and Transfer factor	A coaxial type, HPGe detector	Soil and Crop (yam and cassava).	Wukari and Jalingo, Taraba State	Tyovenda *et. al*., (2022)
^{40}K, ^{232}Th, ^{238}U, Ra_{eq}, H_{ex}, H_{in}, gamma index I_{γ}, gamma absorbed dose D, AEDE, ELCR and Transfer factor	A coaxial type, HPGe detector	Soil and Crops (yam, maize, beans and cassava)	Lafia, Keffi, N/eggon. Doma in Nassarawa State	Ocheje *et. al*., (2021)
^{40}K, ^{232}Th, ^{238}U, Ra_{eq}, gamma absorbed dose D, AEDE, annual effective dose E, Cancer risk, hereditary effect and Transfer factor	NaI (Tl) Scintillation detector	Soil and Crops (cassava, yam, maize, plantain, groundnut, rice, potatoes, banana, beans and cocoyam).	Niger-Delta Region. (Ilaje, Ohosu, Emohua, Ughelli, Obio/Akpor, Odukpani, Adagbabiri, Aba, Eket and Obinnze)	Avwiri *et. al*., (2021)
^{40}K, ^{226}Ra, ^{232}Th, Ra_{eq}, H_{ex}, H_{in}, gamma index I_{γ}, gamma absorbed dose D, AEDE, ELCR and Transfer factor	NaI (Tl) Scintillation detector	Soil and Crops (Ofada rice)	Aramoko (Ekiti State), Abakaliki (Ebonyi State) and Ofada (Ogun State).	Alausa *et. al*., (2020)
^{40}K, ^{226}Ra, ^{232}Th, Ra_{eq}, H_{ex}, H_{in}, gamma absorbed dose D, AEDE, ELCR and Transfer factor	NaI (Tl) Scintillation detector	Soil and food crops (maize, guinea corn, yam and cassava)	Kuru-Jos. Jos-Plateau State.	Alausa (2020)
^{40}K, ^{232}Th, ^{238}U, Effective ingestion dose E, and Transfer factor	NaI (Tl) Scintillation detector	Soil and Crop (cassava)	Ufam and Obot Nduo, Akwa-Ibom State	Essien *et. al*., (2021)
^{40}K, ^{226}Ra, ^{232}Th, gamma dose rate D, Effective ingestion dose E, and Transfer factor	NaI (Tl) Scintillation detector	Soil and Food crops (vegetables, cereals, tubers and legumes)	Bitsichi, Jos-Plateau State	Jibiri *et. al*., (2007)
^{40}K, ^{232}Th, ^{238}U and Transfer factor	NaI (Tl) Scintillation detector	Soil, Plant (grasses) and Cow dung	Mangoro-Agege, Lagos State.	Ilori and Alausa, (2019)

Table 2: Summary of Results obtained by Researchers on studies of transfer factor of NORMs in Nigeria.

Study Area	Activity Conc. in Soil Samples (BqKg^{-1})				Plant/Crop	Activity Conc. in Plant Components/Crops (BqKg^{-1})				Transfer Factor				Reference
	^{40}K	^{238}U/ ^{226}Ra	^{228}Ra	^{232}Th		^{40}K	^{238}U/ ^{226}Ra	^{228}Ra	^{232}Th	^{40}K	^{238}U/ ^{226}Ra	^{228}Ra	^{232}Th	
South-West	393.73	52.91	-	76.79	Stem & leaf	3271.66	25.88	-	19.90	26.58	0.62	-	0.39	Ibikunle *et. al.*, 2019
Delta	413.64	54.53	-	561.67	Food crop	746.08	24.83	-	859.41	1.55	0.99	-	1.66	Ononugbo *et. al.*, 2019
Osun	270.14	12.14	-	23.23	Vegetables & crops	89.41	8.56	-	13.71	0.39	0.73	-	0.61	Oluyide *et. al.*, 2018
Lokoja	508.86	41.27	-	18.90	Crops	38.00	7.45	-	9.08	0.08	0.31	-	0.59	Okeme *et. al.*, 2016
Ibaji	633.54	9.81	-	11.95	Crops	38.71	7.94	-	8.65	0.10	0.81	-	0.87	Okeme *et. al.*, 2016
Iwere-Ile	381.80	25.30	26.20	-	Food crops	128.50	3.70	2.50	-	0.38	0.18	0.11		Ademola, 2019
Komu	401.90	25.40	39.50	-	Crops	143.80	5.60	2.4	-	0.36	0.21	0.06		
Ofiki	394.90	26.50	39.20	-	Crops	139.20	4.70	1.80	-	0.37	0.15	0.05		
Igbeti	389.60	26.50	-	38.80	Crops	147.00	6.6	-	2.3	0.36	0.21	-	0.06	
Ibadan	374.01	242.13	-	1776.08	Seed	105.43	BDL	-	318.46	0.27	BDL	-	0.09	
					Stem	685.08	BDL	-	828.87	1.74	BDL	-	0.29	Adesiji & Ademola, 2019
					Leaf	371.13	80.06	-	304.31	0.93	0.33	-	0.08	
					Root	561.34	245.47	-	1065.80	1.29	1.01	-	0.60	
Eket	109.47	15.96	-	14.35	Crops	-	BDL	-	-	3.56	BDL	-	1.23	
Ogbodu	210.93	9.50	-	14.62	Crops	-	BDL	-	-	1.81	BDL	-	0.95	Azionu *et.al.*, 2021
P/Harcourt	38.27	13.64	-	10.76	Crops	-		-	-	10.83	BDL	-	0.46	
Kachia	537.91	11.24	-	62.25	Ginger	100.81	4.41	-	6.63	0.29	0.40	-	0.17	Adeleke *et. al.*, 2021
Ankwa	493.74	11.60	-	71.97	Tumeric	22.62	2.10	-	6.57	0.09	0.18	-	0.09	
Maikunkele	575.21	48.66	-	51.82	Moringa	105.05	4.61	-	10.17	0.20	0.09	-	0.19	
Mando	418.84	24.42	-	30.20	Goat weed	104.19	6.91	-	10.03	0.31	0.50	-	0.41	
Wukari	199.21	25.37	-	87.23	Crops	82.77	11.00	-	49.75	0.40	0.74	-	0.57	Tyovenda *et. al.* 2022
Jalingo	633.13	71.20	-	141.14	Crops	306.17	11.51	-	12.67	0.51	0.27	-	0.10	
Lafia	309.40	24.80	-	16.75	Crops	142.64	16.78	-	8.67	0.32	0.74	-	0.48	Ocheje et. al., 2021
Keffi	569.33	26.82	-	22.12	Crops	221.14	17.28	-	16.67	0.39	0.64	-	0.75	
N/Eggon	389.71	22.91	-	27.82	Crops	126.98	18.05	-	17.08	0.34	0.45	-	0.36	
Doma	408.69	48.30	-	24.08	Crops	19.26	17.70	-	141.80	0.05	0.37	-	0.37	
Niger Delta Region	164.42	14.97	-	48.53	Crops	96.17	38.44	-	22.85	0.58	2.57	-	0.47	Avwiri et. al., 2021
Ofada	333.90	11.10	-	9.90		261.80	9.60	-	8.70	0.78	0.86	-	0.89	Alausa et. al., 2020
Abakaliki	306.90	10.70	-	9.40		257.20	9.30	-	7.80	0.84	0.92	-	0.83	
Aramoko	321.80	10.80	-	9.50		248.20	9.20	-	7.60	0.77	0.85	-	0.80	

Table 3: Summary of Results obtained by Researchers on studies of transfer factor of NORMs in Nigeria (Contd.)

Study Area	Activity Conc. in Soil Samples (BqKg^{-1})				Plant	Activity Conc. in Plant Components/Crops (BqKg^{-1})				Transfer Factor				Reference
	^{40}K	^{238}U/ ^{226}Ra	^{228}Ra	^{232}Th		^{40}K	^{238}U/ ^{226}Ra	^{228}Ra	^{232}Th	^{40}K	^{238}U/ ^{226}Ra	^{228}Ra	^{232}Th	
Kuru-Jos	989.90	144.40	-	205.40	Guinea corn	351.00	38.00	-	29.90	0.37	0.31	-	0.19	Alausa, 2020
	660.90	105.10	-	197.80	Maize	126.30	26.90	-	31.60	0.23	0.27	-	0.17	
	1261.00	167.50	-	193.70	Yam	456.20	46.90	-	29.50	0.39	0.29	-	0.16	
	1105.60	119.40	-	192.20	Cassava	300.70	33.30	-	24.60	0.29	0.33	-	0.13	
Ufam	99.11	3.60	-	8.64	Cassava	360.40	6.56	-	6.21	3.64	1.82	-	0.72	Essien et. al., 2021
Obot Nduo	93.60	8.96	-	6.12	Cassava	391.13	11.64	-	3.09	4.18	1.30	-	0.51	
Bitsichi	96.50	216.90	-	734.30	Cereals	130.60	9.70	-	3.10	1.35	0.05	-	0.004	Jibiri et. al., 2007
					Tubers	535.90	36.20	-	39.60	5.55	0.17	-	0.05	
					Vegetables	141.40	12.20	-	1.90	1.47	0.06	-	0.003	
					Legumes	466.30	8.40	-	9.70	4.83	0.04	-	0.13	
Agege, Lagos	403.07	11.47	-	10.44	Grass	115.46	10.06	-	8.31	0.29	0.88	-	0.80	Ilori & Alausa. 2019
					Cow dung	184.90	11.50	-	10.20	66.44	1.44	-	1.89	

DISCUSSION

Most of the initial research studies carried out in Nigeria were centred (focussed) on activity concentrations and radiation dose of natural radioactivity in agricultural soils (both in normal and high background areas), and, activity concentrations, committed effective dose and ingestion doses in water (drinking and irrigation), medicinal plants and food crops. However, because of recent developments in research, and the need to go beyond the activity concentrations of natural radioactivity at a particular instant and location alone, then the use of environmental transfer models becomes inevitable. Environmental transfer models depend mainly on transfer factors of these radionuclides to assess, analyse and predict the concentrations of radionuclides in plants at the present and in the foreseeable future. This led to paradigm shift in research studies' interests to soil-to-plant transfer factor of radionuclides, which many research studies in Nigeria were recently focussed on.

Natural radioactivity has been measured in soils (low and high radiation backgrounds), water, plants (medicinal and edible) and food crops in Nigeria using gamma ray spectrometry by majority of the research groups. Thallium-doped sodium iodide scintillation detector was used by many researchers, followed by high purity Germanium detector and thallium-doped Caesium iodide detector, in the estimation of natural radioactivity in various samples. Substantial variation in results of activity concentrations of natural radionuclides were recorded, and this has been attributed to difference in geological formations, geographical conditions, soil types, climatic conditions, climatic distinctiveness and variation in farming techniques/practices (Faheem & Mujahid, 2008; Malik *et. al.*, 2011; Rafque *et. al.*, 2013).

Table 2 shows that the minimum activity concentrations of ^{40}K and ^{226}Ra reported in soil samples among different research studies conducted in Nigeria in different locations were 38.27 BqKg^{-1} and BDL respectively (Azionu *et. al.*, 2021); for ^{228}Ra, 18.0 BqKg^{-1} (Ademola, 2019); for ^{238}U, it was 5.98 BqKg^{-1} (Oluyide *et. al.*, 2018) while 1.03 BqKg^{-1} was recorded for ^{232}Th (Essien *et. al.*, 2021). Whereas the maximum activity concentrations of natural radioactivity reported in soil samples include; 5008.18 Bqkg^{-1} for ^{40}K, 2763.90 BqKg^{-1} for ^{238}U and 26211.90 BqKg^{-1} for ^{232}Th, (Adesiji & Ademola, 2019); 46.2 BqKg^{-1} for ^{228}Ra ((Ademola, 2019) and 470.6 BqKg^{-1} for ^{226}Ra (Jibiri *et. al.*, 2007).

Also, for activity concentrations of naturally occurring radionuclides reported in plant/food crop samples, the minimum values reported by various researchers include: BDL for ^{232}Th, and BDL for ^{226}Ra (Azionu *et. al.*, 2021); BDL for ^{238}U (Adesiji & Ademola, 2019); 1.1 $BqKg^{-1}$ for ^{228}Ra (Ademola, 2019), and 11.70 $BqKg^{-1}$ for ^{40}K (Adeleke *et. al.*, 2021). However, the maximum natural radioactivity reported by different researchers in plant/food crop samples were: 3831.23 $BqKg^{-1}$ for ^{232}Th, and 367.19 $BqKg^{-1}$ for ^{238}U (Adesiji & Ademola, 2019); while 3.1 $BqKg^{-1}$ was reported by Ademola, (2019) for ^{228}Ra; 85.5 $BqKg^{-1}$ for ^{226}Ra (Jibiri *et. al.*, 2007) and 3271.66 $BqKg^{-1}$ for ^{40}K (Ibikunle *et. al.*, 2019).

The minimum values of soil-to-plants/food crops transfer factors reported by different researchers from different sample areas/locations in Nigeria for ^{40}K, ^{226}Ra. ^{228}Ra, ^{232}Th and ^{238}U include: 0.02 (Adesiji & Ademola, 2019; Alausa, 2019); BDL (Azionu *et. al.*, 2021); 0.03 (Ademola, 2019); 0.01 (Alausa, 2020); and, BDL (Oluyide *et. al.*, 2018; Adesiji & Ademola, 2011) respectively. Furthermore, the maximum values of soil-to-plants/food crops transfer factors for ^{40}K, ^{226}Ra, ^{228}Ra, ^{232}Th and ^{238}U as reported in different studies conducted in Nigeria were: 26.58 (Ibikunle *et. al.*, 2019); 6.09 (Avwiri *et. al.*, 2021); 0.14 (Ademola, 2019); 5.08 (Ononugbo *et. al.*, 2019); and, 5.18 (Adesiji & Ademola, 2019) respectively.

The minimum radium equivalent (Ra_{eq}) reported in all the soil samples, used in research studies on soil-to-plant transfer factors in Nigeria, captured by this review was 7.42 $BqKg^{-1}$ (Avwiri *et. al.*, 2021) while the maximum value of 1415.26 $BqKg^{-1}$ was recorded by Ononugbo *et. al.*, 2019). The minimum Internal (H_{in}) and External (H_{ex}) indices recorded in all the soil samples, by various researchers, were 0.10 and 0.08 respectively (Ibikunle *et. al.*, 2019), while the maximum values of H_{in} and H_{ex} reported were 3.96 and 3.82 respectively (Ononugbo et. al. 2019). The lowest value of Absorbed Dose (D) for soil samples reported in all the studies was 12.36 $nGy.h^{-1}$ (Ibikunle *et. al.*, 2019), while the maximum value obtained was 525.5 $nGy.h^{-1}$ (Alausa, 2020). For Excess lifetime cancer risk (ELCR) for the soil samples, the minimum value obtained was 0.16×10^{-3} (Alausa *et. al.*, 2020) while 1.36×10^{-3} was the maximum value obtained in all the studies by Ibikunle *et. al.*, (2019)

CONCLUSION

Studies conducted on soil-to-plant transfer factors of naturally occurring radionuclide materials were compiled, discussed and reviewed in this article. Analysis of data obtained by different research groups' show significant discrepancies in activity concentrations of natural radioactivity in farmlands (soil samples) used by various researchers as well as plants (edible and medicinal) and food crops grown on the soils. Sodium Iodide Scintillation NaI(Tl) detector was employed by majority of the researcher groups (more than 80%) in the analysis of their study samples, while the remaining few used High Purity Germanium (HPGe) detector. The activity concentrations of natural radioactivity in soils samples were generally higher than the values recorded in plant and food crop samples in almost all the research studies considered in the review. About 79% of the values of soil-to-plant transfer factor of ^{40}K in all the studies under review were greater than the recommended value of 3×10^{-1} (NCRP, 1991), while the values of transfer factors reported for ^{232}Th and ^{238}U were greater than the recommended values of 2.1×10^{-4} and 4.9×10^{-3} (IAEA, 1993) respectively in all the studies reviewed in this article.

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