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Determination of the Transfer Factor and Dose Rate of radionuclides in Some Selected Crops in Kogi state, Nigeria.

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Abstract
*Radionuclide activity distribution and transfer factor (TF) in plants are crucial parameters used to assess radioactive contamination in the environment, impact of soil radioactivity on agricultural crops and its risks to humans. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in some selected crops and soils of Kogi state have been determined. The average activity concentration of ^{40}K, ^{232}Th and ^{238}U in crop were 180.18, 25.82 and 30.15 $Bqkg^{-1}$ respectively. The activity concentration of ^{40}K, ^{232}Th and ^{238}U in soil ranges from 218.22 to 626.92 $Bqkg^{-1}$ with an average value of 331.82, 32.76to 118.93 $Bqkg^{-1}$ with average values of 67.38 $Bqkg^{-1}$ and 41.36 to 67.30 $Bqkg^{-1}$ with an average value of 52.84 $Bqkg^{-1}$ respectively. And the values of the transfer factor obtained for ^{40}K, ^{232}Th and ^{238}U were in the range of 0.45 to 0.79 with an average value of 0.35, 0.15 to 0.58 with an average value of 0.56 and 0.28 to 1.09 with an average value of 0.43 respectively. The high value of transfer factor in some locations may be due the long usage of inorganic fertilizers and herbicides in those farms. The average values of radium equivalent activity (Ra_{eq}), absorbed dose rate (D), annual effective dose rate (AEDE), external and internal hazard indices and excess life cancer risk (ELCR) are 174.74 Bqk^{-1}, 79.45 $nGyh^{-1}$, 0.10 $mSvy^{-1}$, 0.47, 0.62 and 0.34 for respectively. These values are within the recommended values by UNSCEAR except for AEDE and ELCR. The mean values of $H_{ex.}$ and H_{in} are less than unity, hence the result does not constitute any significant radiological health risk to the farmers and the community as a whole.***

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I. Introduction

A lot of contaminants in human environment have attracted serious attention in research community all around the world. This is as a result of environmental and human healthconsequences associated with its exposure, especially at levels above the prescribed safetylimits. Natural radioactivity has always been present and broadly distributed in the earth'scrust and the atmosphere, either as primordial radionuclides of uranium (^{238}U) and thorium(^{232}Th) decay series and radioactive potassium (^{40}K), or as cosmic radiations that are producedconstantly in the atmosphere (Samad*et al.,* 2012, Hasan *et al.,* 2013, ferdous *et al.,* 2015) Primordial radionuclides of ^{238}U and ^{232}Th decay series and^{40}K which has extremely long half-lives are ofgreat concern in terms of radiation exposure due to their gamma ray emitting potentials.

There are two mechanisms for the contamination of vegetation, i.e., by root uptake or directly by aerial deposition of fallout radionuclides on plants. It is necessary to carry out an accurate assessment of these radionuclides in the daily used food materials in order to ascertain the degree of risk and deleterious effects to the public health (Alharbi and El-Taher, 2013). The amount of radioactivity in soil is transferred in minute quantities into plants. Plants absorb radionuclides from soil and enter the human body via food.

The supply of plant nutrient is limited and depleted with every harvest leading to a drastic reduction in quality and yield in crop plant. Just like the rest of the world, Nigeria's population is increasing and there is also the need to increase availability of food by increasing the rate of food production via application of chemical fertilizers. The major raw materials for the production of chemical fertilizers must therefore supply the essential nutrients necessary for plant growth. The essential nutrients are Nitrogen, phosphorus and potassium. Natural radioactivity of mainly Uranium-238 (^{238}U), Thorium-232 (^{232}Th) and Potassium-40 (^{40}K) seen in phosphate fertilizers emanate from the phosphate ore, (due to geological reasons) which is the main raw material used for phosphate fertilizer production. The application of phosphate fertilizer globally for increased crop production and land reclamation has risen to more than 30 million tons annually (Ei-Taher and Abbady, 2012).The normal concentration of uranium in phosphate rocks is between 30 and 260 ppm which by far exceeds its abundance in the earth's crust. Theapplication of chemical fertilizers may increase the phosphate and uranium concentration in thesoil thereby increasing the concentration in nutrients.

Kogi state is blessed with a lot of nature resources which has attracted industries like the cement factory, steel industry and many more. The waste and operation of these industries could directly or indirectly

contaminate the soil and crop of the area. And due to long usage of land for agricultural purposes, the land is gradually losing its yielding ability, hence most farmers has now resort to the use of inorganic fertilizers and agrochemical to get high yield. This could also have some harmful effect in the long run if not checked.
The aim of this study is to determine the soil to crop transfer factor (TF) in Kogi state where annually food are produced in large commercial quantity for human consumption, in order to assess the impact of soil radioactivity on agricultural crops and the health implication on human.

II. Material And Methods

Study area

Kogi is a state in the north-central zone of Nigeria with a total area of over 29,833km^2. The state has a population of 4,473,500 (National population census 2011). Agriculture is the mainstay of the economy. There are many farm produce from the state notably coffee, cocoa, palm oil, cashews, groundnuts, maize, cassava, yam, rice and melon.

The State is also rich in mineral resources. Mineral resources include coal, limestone, iron, petroleum and tin. The state is home to the largest iron and steel industry in Nigeria known as Ajaokuta Steel Company Limited and one of the largest cement factories in Africa, the Obajana Cement Factory. Figure 1 shows the map of Kogi state and sample location points.

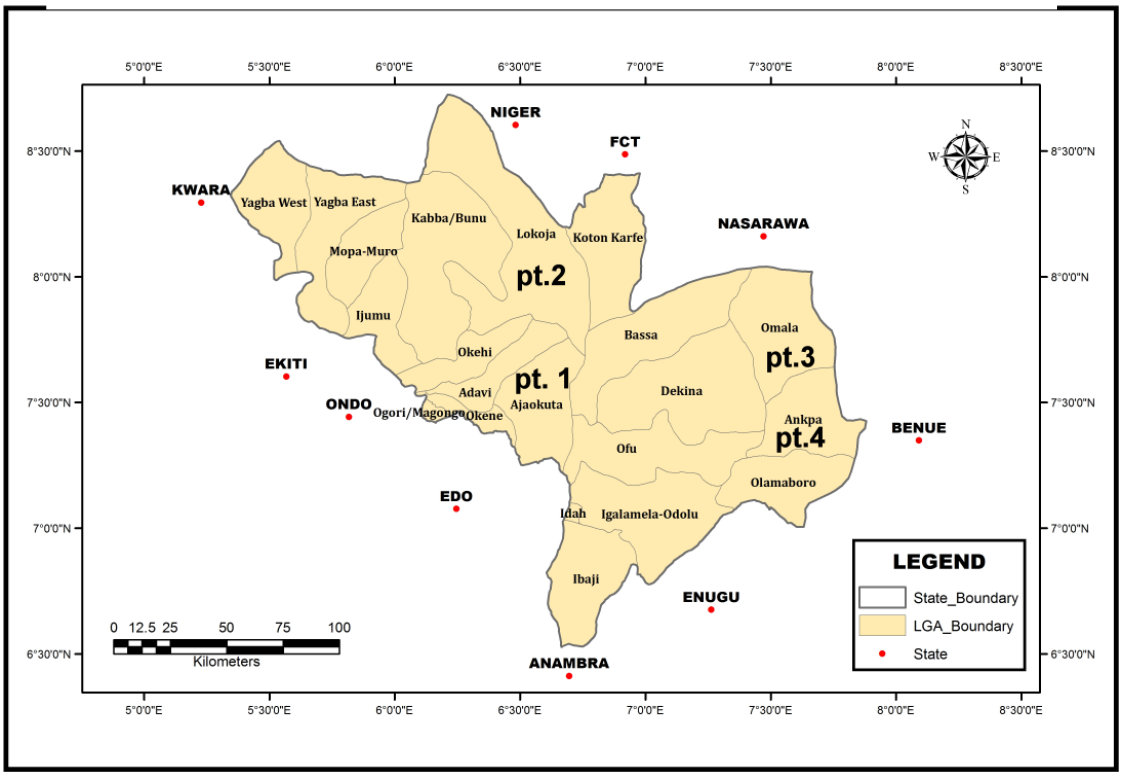

Figure 1: Map of Kogi state showing sample locations

Sample collection

In order to ensure good representative sampling, the entire state was divided into five zones, representing five local government areas, which will be A, B, C, D and E of the sampling sites. Samples of soils were collected from both urban and rural areas across the zones. Eight samples each of soils were collected from each of the zones. At each study location, soils samples were collected from different points in the area .And about one kilogram (1kg) of each sample from each point was collected and placed in a sample bag, labeled and taken to the radiation laboratory sample processing room for subsequent preparation and investigation.

Sample Preparation

Each soil sample was dried under the laboratory condition until constant weight was achieved. The dried samples were then pulverized and homogenized using a motorized grinder and allowed to pass through a

sieve of 200μm mesh size. The homogenized soil samples was dried in a temperature controlled oven at 105^0C for about 24 hours in order to eliminate organic matter content of the soil samples. The samples were then packed and sealed in cylindrical plastic containers to prevent the escape of radiogenic gases such as radon. The weights of the sealed samples were recorded using an electronics weighing balance. In order to achieve radioactive secular equilibrium between parent radionuclides and their respective daughters, the sealed containers were stored for a period of 4 weeks.

Radioactivity measurement

Each sample was placed directly on the HpGe detector and counted for 10 hours. The counting system exhibit high detection efficiency since the number of pulse under a photo peak is proportional to the intensity of the radiation reaching the detector volume. The net area or count under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the peaks from the net area. The background counts in the detector assembly were determined using an empty container sealed under identical measurement conditions and having the same geometry as the container used for the sample measurement. This was determined prior to the measurement of the samples. The procedure was important because of the existence of natural radionuclides in building materials, cosmic rays entering the atmosphere and contribution from other radioactive sources which might be present in the laboratory.

Evaluation of Radiological Parameters: The absorbed dose rate in air at 1m above the ground surface were calculated based on the recommendation given by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000). This quantity was used to measure the radiation exposure to human body in order to evaluate the amount of radiological hazards to humans due to the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil. The absorbed dose rate at 1m above the ground (in nGyh^{-1}) was calculated using the expression (Maphoto, 2004)

$$D\ (nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_k \quad (1)$$

Where; A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The annual effective dose

In order to determine the radiological impact of the results obtained, the annual effective dose was determined for an individual exposed at the calculated dose rate. This was evaluated by converting the total absorbed dose in nGyh^{-1} and multiplies by occupancy factor OF, of one year expressed in seconds. Thus;

$$E = DR\ X\ OF\ X\ CF \quad (2)$$

where; E is the annual effective dose, CF is the conversion factor for absorbed dose in air to external effective dose in adults and is given as 0.7 Sv/Gy, DR is the calculated absorbed dose rate at 1m above the ground and OF is the occupancy factor, which has the value 0.2 (assuming that individuals spend 20% of their time outdoors) × number of hours per annum.

Radium equivalent activity

The radium equivalent activity is a single quantity that is used to account for the radiation doses accruing from ^{226}Ra, ^{232}Th and ^{40}K. It is one of the mostly used hazard indices in radiation protection assessment (Abd El-Hadi et al., 2012). From the expression in equation 3, it has been assumed that 4810 BqKg^{-1} is for ^{40}K, 259 Bqkg^{-1} for ^{232}Th and 370 Bqkg^{-1} for ^{226}Ra.^{238}U and ^{226}Ra produce the same gamma dose; hence the assumed activity value is used for ^{226}Ra and ^{238}U interchangeably. Radium equivalent activity was calculated from the relation(Beretka and Mathew, 1985) :

$$Ra_{eq} = 0.077A_k + A_{Ra} + 1.43A_{Th} \quad (3)$$

where, A_{Ra} is the activity concentration of^{226}Ra in Bq kg^{-1}, A_{Th} is the activity concentration of ^{232}Th in Bq kg^{-1} and A_K is the activity concentration of ^{40}K in Bq kg^{-1}. Internal radiation hazard index (H_{in}) The internal radiation hazard index (H_{in}) was used to reduce the maximum permissible concentration of ^{226}Ra to half the values appropriate for the external exposure alone. The radionuclide radon-222 which is a progeny of ^{226}Ra poses threats to the respiratory organs, when accumulated in large quantity in the indoor air. For the safe use of a material in the construction of dwellings, the maximum value of the internal hazard index should be less or equal to unity. The internal exposure to ^{222}Rn and its radioactive daughters can be controlled by the internal hazard indices. The internal hazard index was calculated using the expression:

$$H_{int} = \frac{A_k}{4810} + \frac{A_u}{185} + \frac{A_{Th}}{259} \leq 1 \quad (4a)$$

A_{Ra}, A_u and A_K are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1}, respectively. The external hazard index due to gamma radiation was calculated using the equation;

$H_{ext.} = \frac{A_k}{4810} + \frac{A_u}{185} + \frac{A_{Th}}{259} \leq 1$ (4b)

Where; A_{Ra}, A_{Th} and A_K are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. The external hazard index was gotten from the expression of the radium equivalent through the supposition that its maximum permissible value corresponds to the upper limit of Ra_{eq} (370Bq/kg), therefore the external dose rate does not exceed 1.5 mGy/y. In order to limit the external gamma dose of materials to 1.5 mGy/y for the radiation hazard to be negligible or insignificant, the external hazard index must be in conformity with the criterion of $H_{ext.} = \leq 1$.

Transfer factor

Radionuclide uptake by plants from contaminated soil represents a key step of radionuclide input into human food chain; this phenomenon is described by soil-plant transfer factor that is defined as the ratio between plant specific activity and soil specific activity. Plants are theprimary recipients of radioactive contamination to the food chain following atmospheric releases ofradionuclides. The transfer factor (TF) is a value used in evaluation studies on impact of routine or accidental releases of radionuclide into the environment. The soil to-plant transfer factor is regarded as one of the mostimportant parameters in environmental safetyassessment needed for nuclear facilities. Thisparameter is necessary for environmental transfermodels which are useful in prediction of theradionuclide concentrations in agriculture crops forestimating dose intake by man (Abdulaziz and El-Taher, 2013).

The soil-to-plant (TF), which is the ratios of specific activities in plant to soil were calculated according to the equation 5 (Harb et al., 2014):

$TF = \frac{C_p}{C_S}$ (5)

where A_P is the activity concentration of radionuclides in plant($Bqkg^{-1}$dryweight) and A_s is the activity concentration of radionuclides insoil ($Bqkg^{-1}$dry weight).

III. Results

The result of the analysis and evaluations carried out on samples are as tabulated below;

Table1: Average activity concentrations of radionuclides in soil sample in Kogi state

LGA	$^{238}U(BqKg^{-1})$	$^{232}Th(BqKg^{-1})$	$^{40}K(BqKg^{-1})$
Ajoakuta	41.3600	37.6733	626.9225
Lokoja	61.2967	118.9333	218.2225
Omala	67.2950	80.1500	227.5975
Ankpa	41.4250	32.7550	254.5200
Mean	52.8442	67.3780	331.8156

Table 2: Average activity concentration of radionuclides in crop sample in Kogi state

LGA	$^{238}U(BqKg^{-1})$	$^{232}Th(BqKg^{-1})$	$^{40}K(BqKg^{-1})$
Ajoakuta	16.905	20.9067	280.48
Lokoja	66.82	17.46	170.165
Omala	18.945	46.735	180.215
Ankpa	17.92	18.19	89.8775
Mean	30.1475	25.8230	180.1844

Table 3 : Average Transfer factor of radionuclides from soil to crops in Kogi state

LGA	TF(U)	TF(Th)	TF(K)
Ajaokuta	0.408728	0.554946	0.447392
Lokoja	1.090108	0.146805	0.779778
Omala	0.281522	0.583094	0.791814
Ankpa	0.432589	0.555335	0.353125

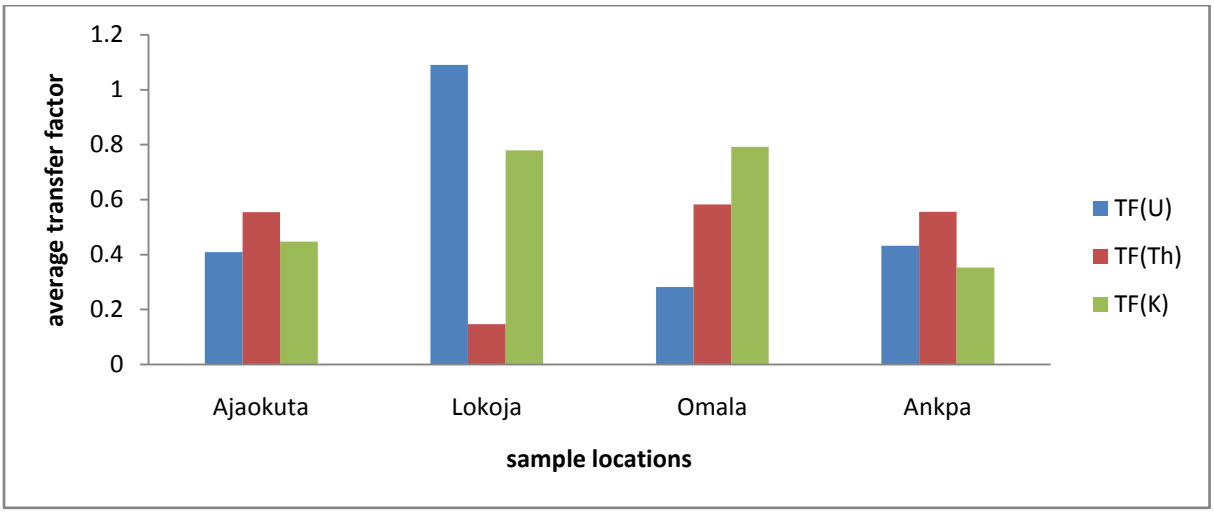

Figure 2: graph of average transfer factor from soil to crops in Kogi state

Table 4: Radiological hazard indices of radionuclides in soil samples from farm lands in Kogi state

Locations	Absorbed dose(nGy/h)	Annual effective dose Rate (mSv)	Ra_{eq}(Bq/kg)	H_{ext}	$H_{int.}$	ELTCR (x 10^{-3})
Ajaokuta	68.94606533	0.084603717	143.5059	0.3876	0.4994	0.296113009
Lokoja	109.5820053	0.134468079	248.1745	0.6702	0.8359	0.470638276
Omala	89.333102	0.109620649	199.4345	0.5387	0.7205	0.383672273
Ankpa	49.917634	0.061253929	107.8627	0.2913	0.4033	0.21438875
mean	79.44470167	0.097486593	174.7444	0.47195	0.614775	0.341203077

Table 5 : Physcio-chemical properties of agricultural soils in Kogi state

Sample locations	Clay(%)	Silt(%)	Sand(%)	pH level	Organic matter (%)
Ajaokuta	10 - 15	20 - 35	75 - 85	5.6 – 6.2	0.56 – 1.02
Lokoja	10 - 18	22 - 34	60 - 76	4.6 – 6.2	0.64 – 1.64
Omala	20 - 24	10 - 20	60 - 68	5.8 – 6.1	0.84 – 1.78
Ankpa	10 - 20	26 - 40	55 -65	4.8 – 6.9	0.86 – 1.86

IV. Discussion

Activity concentration in soil

The activity concentration of radionuclides result shows that the activity concentration of ^{40}K ranges from 227.60to 629.92 $BqKg^{-1}$ with an average value of 331.82 $BqKg^{-1}$, the value is within the world average of 400 $BqKg^{-1}$, the values for ^{232}Th ranges from 32.75 to 118.9 $BqKg^{-1}$ with an average value of 67.37 $BqKg^{-1}$ which is two times above the world average of 30 $BqKg^{-1}$and the activity concentration value for ^{238}U in the area ranges from 41.36 to 67.30 $BqKg^{-1}$with an average value of 52.84 $BqKg^{-1}$, this also is above the world average value of 35 $BqKg^{-1}$. The high value of ^{232}Th and ^{238}U recorded in some the areas could be as a result of the mineral deposit and the use of organic fertilizer and herbicides for agricultural purposes. If the trend is not monitored, it could leads to radiological hazards.

The radiological health risk

The radiological health risk parameters calculated from activity concentration ofradionuclides in the soil are presented in Table 4. The average values of radium equivalent activity (Ra_{eq}), absorbed dose rate (D), annual effective dose rate (AEDE), external and internal hazard index and excess life cancer risk (ELCR) are 174.74 Bqk^{-1}, 79.45 $nGyh^{-1}$, 0.10 $mSvy^{-1}$, 0.47, 0.62 and 0.34 for respectively. These values are within the corresponding permissible values except for (AEDE) and ELCR that their values are above the recommended values as published by (UNSCEAR, 2000). The recommended value for Radium equivalent is 370Bqk^{-1}, for absorbed dose is 55$nGyh^{-1}$, for (AEDE) is 1.0 $mSvy^{-1}$, and for ELCR is 0.29 x 10^{-3} respectively. The mean values of $H_{ex.}$ and H_{in} are less than unity, hence does not constitute any significant radiological health risk.

Transfer factor

The average Transfer factor for the area shows that the value for ^{40}K ranges from 0.35 to 0.79 with an average value of 0.35 that of^{232}Thranges 00.15 to 0.58 and^{238}Uthe ranges from 0.28 to 1.09 with an average value of 0.43. The variations in the TF could be due to differences in soil type, pH, organic matter and other related factors (Table 5).

The high value of TF of ^{238}U recorded in Lokoja may long use of inorganic fertilizers of in the area and due to its higher accumulation in soil and higher uptake by plants. Although the results of activity concentration of natural radionuclide in the area under study are high except for potassium 40, the rate at which they are transferred to crop are still moderate. A lot of care must be taken in the use of transfer factor to determine food safety for consumption in communities, this is in agreement with the observations made by Al-masri *et al.*,(2008). From the definition of transfer factor, it is assumed that the crop activity concentration increases with increased soil activity concentration. The result of this work shows the opposite of this assumption. For example, the average activity concentration of ^{238}U in soil sample from Omala was 67.30 $Bqkg^{-1}$ with a transfer factor of 0.28 while that of Lokoja is 61.30 Bqkg-1 with a transfer factor of 1.09 (Fig.1). The TF result of this work buttresses the fact that TFs are not linearly related to soil concentration which also is in agreement with the conclusion made by Ononugboet al., (2019).

V. Conclusion

The activity concentration of soil sample of ^{238}U and ^{232}Th in studied area is above the recommended average value of 35 $BqKg^{-1}$for ^{238}U and 30 $BqKg^{-1}$for ^{232}Th and the value obtained for ^{40}K was within the recommended value 400 $BqKg^{-1}$ (UNSCEAR, 2000).The TF result of this work buttresses the fact that TFs are not linearly related to soil concentration which also is in agreement with the conclusion made by Ononugboet al., (2019). Many factors could have accounted for this variation. It may be due to the physiochemical characteristics of soil such as; soil pH and fertility, crop type, organic matter content and soil management practices. From the result obtained in this work, root tubers record higher activity concentrations than cereal crops, this may be because the root tuber have direct contact with the soil and spend more time to mature than the cereal crops while for the cereal crops nutrients take some time to travel through stem before getting to the seed and mature faster than many of the tubers like yam and cassava.

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