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# Assessment of the radiological health risk from radionuclide presence and transfer factor from soil to corn in some selected non-oil producing riverine areas of Akwa Ibom state

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## Abstract

The main objective of this study was to estimate the activity concentration (AC) of $^{238}U$, $^{232}Th$ and $^{40}K$, assess the health risk information from radionuclides presence in the soil and corn and the transfer influence from soil to corn. The key device used for the analysis was a Sodium Iodide Thallium detector. $^{238}U$ AC in soil ranges from 14.09±0.27 $Bqkg^{-1}$ to 18.70±0.31 $Bqkg^{-1}$ with mean value of 15.69±0.28 $Bqkg^{-1}$; $^{238}U$ AC in corn varies from 9.36±0.22 $Bqkg^{-1}$ to 14.78±0.27 $Bqkg^{-1}$ with mean value of 11.53±0.24 $Bqkg^{-1}$. $^{232}Th$ AC in soil is from 12.32±0.46 $Bqkg^{-1}$ to 48.76±0.91 $Bqkg^{-1}$ with mean value of 35.97±0.76 $Bqkg^{-1}$. $^{232}Th$ AC in corn ranges from 8.26±0.37 $Bqkg^{-1}$ to 35.19±0.77 $Bqkg^{-1}$ with average value of 17.86±0.53 $Bqkg^{-1}$. $^{40}K$ values from the soil samples varies from 313.61±6.81 $Bqkg^{-1}$ to 472.63±8.36 $Bqkg^{-1}$ with mean value of 384.672±7.52 $Bqkg^{-1}$. $^{40}K$ varies from 374.85±7.45 $Bqkg^{-1}$ to 478.55±8.41 $Bqkg^{-1}$ with average value of 425.51±7.93 $Bqkg^{-1}$from corn samples. The mean transfer factor for $^{238}U$, $^{232}Th$ and $^{40}K$ was obtained as 0.73, 0.62 and 1.13 respectively. The mean values for the Radium equivalent, absorbed dose, annual effective dose, and excess lifetime cancer risk from soil are 96.75 $Bqkg^{-1}$, 47.05 $nGyh^{-1}$, 0.06 $mSvy^{-1}$, $0.20\times10^{-3}$ correspondingly [values from corn are 69.83 $Bqkg^{-1}$, 35.04 $nGyh^{-1}$, 0.04 $mSvy^{-1}$, $0.15\times10^{-3}$ respectively]. These values clearly showed, the radiation doses exposed to Akwa Ibomites through the consumption of corn cultivated in these areas and inhalation of soil poses no effect to their health. Therefore, there is no radiological risk of ingestion.

**Keywords:** Radionuclides; Transfer Factor; Corn; Soil; Activity; Health Risk

## 1. Introduction

Radioactive materials are materials that contain atoms which are prone to instability, therefore disintegrate releasing ionizing particles (Thomas, 2005). This disintegration enables the unstable atomic elements to release ionizing particles such as helium atoms otherwise known as alpha particles, electron and positron otherwise known as beta particles, photons such as x-ray/gamma rays or other forms of photons or radiation. The particles released during this disintegration could be dangerous to living organisms especially if they are exposed to it for an extended period of time. These radioactive materials can be found naturally in the environment such as in rocks and soil or they can be artificially produced in laboratories or nuclear reactors. Radionuclides are introduced in the soil (which may be important in the yield of our planet ecosystems (Atat *et al.,* 2017)). Some common examples of radioactive materials include $^{238}U$, $^{232}Th$ and $^{40}K$. (NRC, 1999). The concentration of the different naturally occurring radioelements which have been present in the earth crust since its inception varies in types and quantities in different locations depending on the rock formation in the area or the activities that have been carried out in that area. These activities include addition of chemical fertilizers (especially phosphate fertilizers which contains heavy metals including Cd, Cr, Pb and radioactive elements like Uranium, Thorium and their daughters (Mortvedt and Sikora, 1992)) to the soil, and pesticides and herbicides.

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Other researchers with related studies include Akankpo *et al*. (2021), Essien et al. (2021) and Ejoh et al. (2023) who also determined the transfer factor for different cases. Benjamin et al. (2022) studied transfer factor of soil to vegetable. Ekpo et al. (2021) and Ekpo et al. (2020) correspondingly, studied the effect of exploration activities on mineral elements and the information on ionizing radiation in swamp rice farm. Essien et al. (2016) assessed the radioactive elements concentrations in soils. According to Ejoh et al. (2023), the presence of radioactivity in the edible parts of crops causes human internal exposure to $^{226}$Ra and $^{232}$Th which are radiotoxic elements; $^{40}$K is both radiotoxic and nutritionally significant (Rilwan et al., 2022). $^{40}$K (potassium) helps cells, nerves and muscles discharge their tasks effectively (Ekpo et al., 2021), and supports the body to control blood pressure, heart rhythm and volume of water in cells as well as digestion (Ekpo et al., 2021).

The main goal of the study is to evaluate the level of contamination of corn and soil by $^{238}$U, $^{232}$Th and $^{40}$K using Sodium Iodide-Thallium Gamma-ray Spectroscopy, the transmitting ability of the radioelements from soil to maize and the health risk associated with the consumption and inhalation of it. These radionuclides concentration can be determined using several measurement techniques which include Sodium Iodide-Thalium (NaI(TI)) and High Purity Germanium (HPGe) detectors. Sodium Iodide-Thallium Gamma Spectroscopy is most needed when high detection efficiency and a wide range of energy is needed as they can detect gamma rays from a wide range of energy that can span from few kilo-electron volt to several mega-electron volt and have a larger sensitive volume. (Rahim et al., 2019).

### 1.1. Location of the Study Area


**Figure 1** The study area chart highlighting the coastal areas in Akwa Ibom State

One of the states in the down south part of Nigeria is Akwa Ibom. The state is about Latitude $4^0$ $32^0$N and $5^0$ $33^0$N and Longitude $7^0$ $25^0$E and $8^0$ $25^0$ E (Figure 1) (Benjamin et al., 2022). It is located in the Niger Delta region (Figure 1). Niger Delta lies between latitudes $3^0$N and $6^0$N; longitudes $5^0$E and $8^0$E (Atat et al., 2020a; 2020b) and characterized by two distinct seasons: the rainy (March - October) and dry season (November - February) (Atat and Umoren, 2016; Atat et al., 2020b). Akwa Ibom State is in the southern coastal region of Nigeria; it has a border between Nigeria and the Atlantic Ocean. The average rain in a month during wet season is about 135 mm and falls to 65 mm during dry season (Atat et al., 2020c). About five local government areas in the state are studied which are bordered by very large bodies of water. These local government areas include: Itu, Okobo, Oron, Uruan and Udung Uko.

## 2. Materials and Methods

### 2.1. Sample Collection, Preparation and Analysis

Corn and soil samples were obtained from 10 locations in the riverine areas of the State. Random sampling technique was employed to achieve statistical sensitivity of samples (IAEA, 2010). Three or more corns were harvested depending on the corn size and inserted into a black nylon bag and labelled appropriately. 2kg of soil was obtained about 25 to 30cm deep near the plant and labelled to define the location and name of the site (Essien et al., 2017; Essiett et al., 2022). The corn seeds were plucked out, sundried, pulverized, sieved through a 1mm sieve to obtain very fine powder. The corn powder was further dried to completely remove any moisture content in an oven at about $110^0$C for 1 hour. The soil samples were air dried, ground, sieved and packed. The samples were sent to the Energy Research and Development Center at Obafemi Awolowo University Ile-Ife for analysis of $^{238}$U, $^{232}$Th, $^{40}$K using a Sodium Iodide-Thalium (NaI(TI)) detector.

### 2.2. Activity Concentration and Transfer Factor

The estimation of the activity concentration may be achieved using Equation 1 (Essien et al, 2021). Equation 2 was adequate for the determination of transfer factor (Benjamin et al. 2022; Ejoh et al., 2023). It is a dimensionless quantity.

$$C = \frac{N}{\xi t \gamma M} \quad (1)$$

Where M is the mass of the samples measured in kg, $\xi$ is the detector energy dependent efficiency, t is the counting time 36,000 s (10 hours), $\gamma$ is the gamma ray yield per disintegration of the nuclides, N is the net peak area of the nuclide.

$$TF = \frac{C_P}{C_S} \quad (2)$$

Where $C_P$ is the concentration of radionuclides in plant (corn); $C_S$ is the concentration of radionuclide in soil.

### 2.3. Radium Equivalent Activity and Absorbed Dose Rate in Air

Radium equivalent activity is expressed in units of Becquerel per kilogram (Bqkg$^{-1}$) and represents all radionuclides present in a material that emits equivalent gamma dosage as $^{226}$Radium and its decay products. Equation 3 is adequate for the assessment of this activity. Absorbed dose rate in air is the dose received by a person in the surrounding exposed to radioactive materials; it was calculated using Equation 4 considering the height of about 1 meter above the ground level.

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K \quad (3)$$

$$D_\gamma = 0.427C_U + 0.662C_{Th} + 0.043C_K \quad (4)$$

Where $C_U$, $C_{Th}$, $C_K$ are the average concentration of $^{238}$U, $^{232}$Th, $^{40}$K respectively. $D_\gamma$ is the absorbed dose rate in air, (nGyh$^{-1}$),

### 2.4. Annual Effective Dose

Annual effective dose was computed to help assess the health effects of the absorbed dose (UNSCEAR, 1993). This was carried out using the conversion coefficient of 0.7SvG/y to transform absorbed dose in air to the effective dose received by human beings. 0.2 was used as the outdoor occupancy factor (UNSCEAR, 1993). Equation 5 was used for the calculation of the annual effective dose (Essien, *et al.,* 2017).

$$AED = D\gamma \times 8760 \times 0.7 \times 10^{-6} \times 0.2 \quad (5)$$

Where AEDR ($mSvy^{-1}$) is the annual effective dose rate, Dγ($nGyh^{-1}$) is the absorbed dose rate, $8760h^{-1}$ is the hours of time in a year, $0.7SvGy^{-1}$ is the conversion coefficient from absorbed dose to effective dose received by adults and $10^{-6}$ is the conversion factor between nano and milli. The AED recommended world mean value is unity

### 2.5. Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk is a term that is used to determine the potential carcinogenic effects one could be exposed to if they consume corn for a long time (about 70 years). This was calculated using Equation 6.

$$ELCR = AED \times RF \times DL \quad (6)$$

Where AED represents the annual effective dose due to consumption of food crops, RF is the fatal cancer risk factor which is 0.05 for the public (UNSCEAR, 2000) and DL is the duration of life which is 70 years for Nigeria. The ELCR recommended world mean value is 0.0029 (UNSCEAR, 2000).

## 3. Result

The goal of this research is to assess the radiological health risk from radionuclide presence and transfer factor from Soil to corn, The results obtained for $^{238}U$, $^{232}Th$ and $^{40}K$ activity concentration of soil and corn in these areas are presented in Table 1. Figures 2 and 3 simplified this information in a pie chart. Table 2 information is adequate for computed radiological risk from corn samples. Results computed for radiological risk of soil samples is in Table 3. Table 4 presents the transfer factor results from soil to corn. Figure 4 compares the transfer factors of these radionuclides with their corresponding locations.

**Table 1** Radionuclides activity concentration in soil and corn samples

| **LGA** | **Soil** | | | **Corn** | | |
|---|---|---|---|---|---|---|
| **LGA averages** | **K-40 ($Bqkg^{-1}$)** | **U-238 ($Bqkg^{-1}$)** | **Th-232 ($Bqkg^{-1}$)** | **K-40 ($Bqkg^{-1}$)** | **U-238 ($Bqkg^{-1}$)** | **Th-232 ($Bqkg^{-1}$)** |
| Itu | 472.63±8.36 | 18.70±0.31 | 41.19±0.83 | 374.85±7.45 | 14.78±0.27 | 35.19±0.77 |
| Okobo | 370.41±7.40 | 14.09±0.27 | 48.76±0.91 | 478.55±8.41 | 10.04±0.23 | 8.26±0.37 |
| Oron | 425.00±7.93 | 15.78±0.28 | 44.53±0.87 | 468.24±8.33 | 9.36±0.22 | 10.72±0.42 |
| Udung Uko | 341.71±7.11 | 15.63±0.28 | 12.32±0.46 | 409.32±7.78 | 12.01±0.24 | 15.17±0.50 |
| Uruan | 313.61±6.81 | 14.26±0.27 | 33.06±0.75 | 396.59±7.66 | 11.45±0.24 | 19.96±0.58 |
| Average | 384.672±7.52 | 15.69±0.28 | 35.97±0.76 | 425.51±7.93 | 11.53±0.24 | 17.86±0.53 |
| Minimum | 313.61±6.81 | 14.09±0.27 | 12.32±0.46 | 374.85±7.45 | 9.36±0.22 | 8.26±0.37 |
| Maximum | 472.63±8.36 | 18.70±0.31 | 48.76±0.91 | 478.55±8.41 | 14.78±0.27 | 35.19±0.77 |
| WPA (UNSCEAR,2000) | 420 | 33 | 45 | - | 0.02 | 0.003 |

**Table 2** Computed radiological risk from corn samples

| LGA averages | Raeq ($Bqkg^{-1}$) | Absorbed Dose Rate ($nGyh^{-1}$) | Annual Effective Dose ($mSvy^{-1}$) | ELCR ($\times10^{-3}$) |
|---|---|---|---|---|
| Itu | 93.97 | 45.73 | 0.06 | 0.20 |
| Okobo | 58.70 | 30.33 | 0.04 | 0.13 |
| Oron | 60.74 | 31.23 | 0.04 | 0.13 |
| Udung Uko | 65.22 | 32.77 | 0.04 | 0.14 |
| Uruan | 70.53 | 35.16 | 0.04 | 0.15 |
| Average | 69.83 | 35.04 | 0.04 | 0.15 |
| Minimum | 58.70 | 30.33 | 0.04 | 0.13 |
| Maximum | 93.97 | 45.73 | 0.06 | 0.20 |

**Table 3** Computed radiological risk of soil samples

| LGA | Raeq ($Bqkg^{-1}$) | Absorbed Dose Rate ($nGyh^{-1}$) | Annual Effective Dose ($mSvy^{-1}$) | ELCR ($\times10^{-3}$) |
|---|---|---|---|---|
| Itu | 113.99 | 55.58 | 0.07 | 0.24 |
| Okobo | 112.34 | 54.22 | 0.07 | 0.23 |
| Oron | 112.18 | 54.49 | 0.07 | 0.23 |
| Udung Uko | 59.56 | 29.52 | 0.04 | 0.13 |
| Uruan | 85.68 | 41.46 | 0.05 | 0.18 |
| Average | 96.75 | 47.05 | 0.06 | 0.20 |
| Minimum | 59.56 | 29.52 | 0.04 | 0.13 |
| Maximum | 113.99 | 55.58 | 0.07 | 0.24 |

**Table 4** Transfer factors from soil to corn determined

| LGA | TF $^{238}U$ | TF $^{232}Th$ | TF $^{40}K$ |
|---|---|---|---|
| Itu | 0.79 | 0.85 | 0.79 |
| Okobo | 0.71 | 0.17 | 1.29 |
| Oron | 0.59 | 0.24 | 1.10 |
| Udung Uko | 0.77 | 1.23 | 1.20 |
| Uruan | 0.80 | 0.60 | 1.26 |
| Average | 0.73 | 0.62 | 1.13 |
| Minimum | 0.59 | 0.17 | 0.79 |
| Maximum | 0.80 | 1.23 | 1.29 |

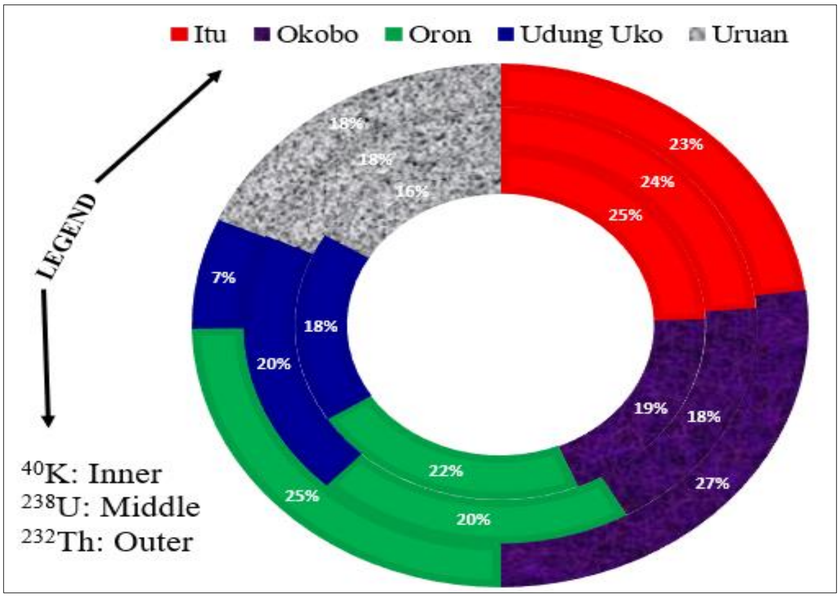


**Figure 2** Soil AC Distribution

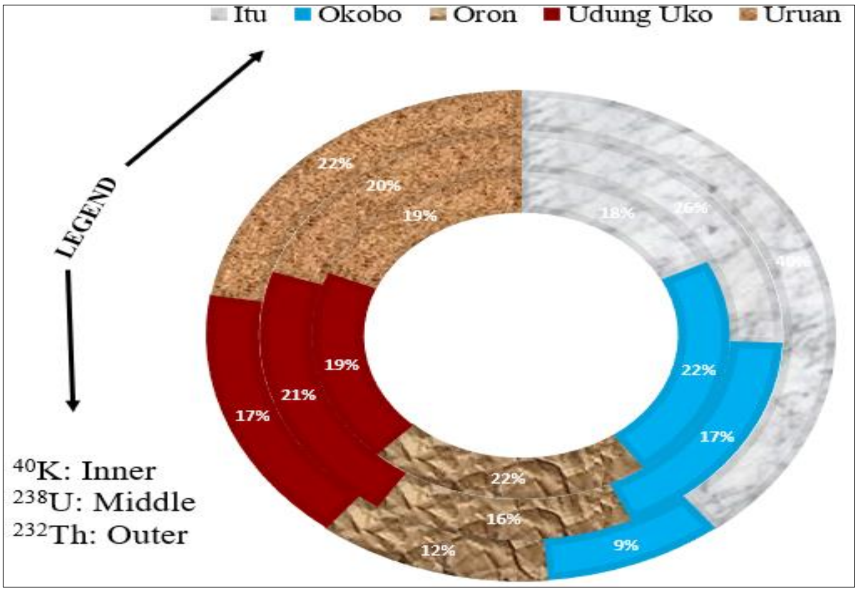


**Figure 3** Corn AC Distribution

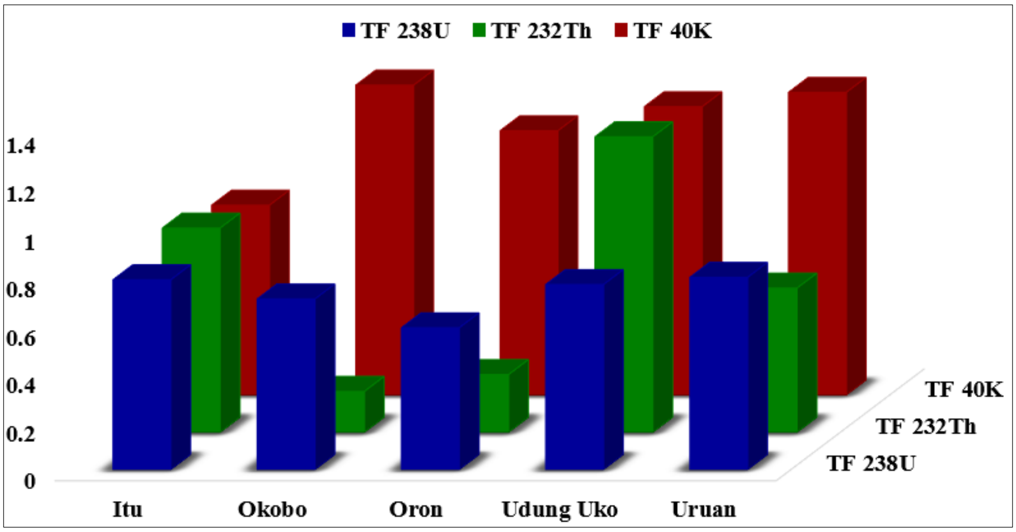


**Figure 4** Transfer Factor Distribution of the three Radionuclides for each LGA.

## 4. Discussion

### 4.1. Activity concentration in soil and corn

The soil AC was analyzed in the study area. The results from Table 1 shows that the $^{238}U$ AC in soil ranges from 14.09±0.24 to 18.70±0.31 with mean value of 15.69±0.28 Bqkg$^{-1}$, $^{238}U$ AC in corn varies from 9.36±0.22 to 14.78±0.27 with mean value of 11.53±0.24 Bqkg$^{-1}$. Itu has the maximum value of $^{238}U$ AC in soil (18.70±0.31 Bqkg$^{-1}$) and Uruan has the minimum $^{238}U$ AC in soil of 14.26±0.27 Bqkg$^{-1}$. From corn, Itu has the maximum $^{238}U$ AC of 14.78±0.27 Bqkg$^{-1}$ and Oron has the minimum $^{238}U$ AC in corn of 9.36±0.22 Bqkg$^{-1}$. The average $^{232}Th$ AC in soil is 35.97±0.76 Bqkg$^{-1}$ with Okobo having the maximum of about 48.76±0.91 Bqkg$^{-1}$ and Udung Uko with the minimum value of 12.32±0.46 Bqkg-$^{1}$. The average $^{232}Th$ AC in corn was obtained as 17.86±0.53 Bqkg$^{-1}$, Itu has the highest value of 35.19±0.77 Bqkg$^{-1}$ and Okobo has the lowest value of 8.26±0.37 Bqkg$^{-1}$. $^{40}K$ mean AC of soil is about 384.672±7.52 Bqkg$^{-1}$ with Itu having the highest of 472.63±8.36 Bqkg$^{-1}$ and Uruan with the minimum value of 313.61±6.81 Bqkg$^{-1}$. $^{40}K$ mean AC from corn is obtained as 425.51±7.93 Bqkg$^{-1}$. Okobo has the highest $^{40}K$ AC in corn of about 478.55±8.41 Bqkg$^{-1}$ and Itu with the lowest value of 374.85±7.45 Bqkg$^{-1}$. Corn AC for $^{238}U$ and $^{232}Th$ was far above the world permissible limit (UNSCEAR, 2000). The numerical proportions are highlighted clearly in Figures 2 and 3. From the mean values, the most dominant radionuclide out of the three investigated in the study area is $^{40}K$.

$^{40}K$ highest concentration in this work is in consonance with the trend observed in most previous works within the state (Akankpo *et al.*, 2021; Essien *et al.*, 2021; Essien and Akpan, 2016) as well as outside the state (Adesiji and Ademola, 2019), Jibiri *et al.,* 2007; Mgbeokwere *et al.,* 2021; Ocheje and Tyovenda, 2020) and outside Nigeria (Kiplangat, 2016). The high Potassium concentration contributions could be due to the fact that not only that Potassium is a primordial radionuclide that is dominant in soil as well as human beings, but it is also majorly present in fertilizers which is used to improve soil quality and subsequently increase crop yield. Though Uranium and Thorium were significantly lower in concentration compared to Potassium, they are present in all the soil and corn samples that were used in this work contrary to other research papers (Akankpo *et al.,* 2021; Essien and Akpan, 2016; Essiet *et al.,* 2022) which presented Uranium and Thorium in some samples as Below Detection Level (BDL) and Not Detected (ND) in some cases. Uranium as well as Thorium availability in corn and soil samples can be related to the not only the fact the Uranium and Thorium also occur naturally but they are also contained in phosphate fertilizers as the basic constituent of most fertilizers are Nitrogen, Phosphorus and Potassium. Ei-Taher and Abbady (2012) has it that phosphate fertilizer application globally has contributed immensely in land reclamation and increased crop production by excess of 30 million tons yearly. Therefore, chemical fertilizers added to the soil will improve these uranium as well as phosphate levels because normal Uranium concentration available in rocks of Phosphate lies around 30 to 260 ppm (Ocheje and Tyovenda, 2020). Uranium also decays into Thorium; therefore, contributions of Thorium will continue to be slightly higher than Uranium over time. However, a very high percentage of activity concentration of Thorium about 40% is noted from corn samples in Itu local government area

### 4.2. Transfer Factor of Radionuclides from Soil to Corn

Equation 2 was employed to determine the transfer factor; Figure 4 shows the graphical representation of these results. Mean TF of $^{40}K$, $^{238}U$ and $^{232}Th$ from soil to corn are 1.13 ± 0.10, 0.73 ± 0.04 and 0.62 ± 0.21 respectively. The range of values of $^{40}K$, $^{238}U$ and $^{232}Th$ varies as 0.79 to 1.29, 0.59 to 0.80 and 0.17 to 1.23 correspondingly. The value of TR is accredited to the richness of the organic matter in the soil. The mean transfer factor obtained indicates that the value is less than the world recommended value of unity and 5.60 (UNSCEAR, 2020) respectively for thorium and potassium.

### 4.3. Radium Equivalent

Equation 3 was employed to determined radium equivalent. Table 2 and Table 3 displayed these results with highest and lowest values of 113.99 $Bqkg^{-1}$ and 59.56 $Bqkg^{-1}$ respectively from soil as well as 93.97 $Bqkg^{-1}$ and 58.70 $Bqkg^{-1}$ as highest and lowest values noted from corn. It is seen that the activity concentration in the soil is higher than that of the corn. However, the Raeq in all the local government areas are far lower than the world permissible limits of 370 $Bqkg^{-1}$ (UNSCEAR, 2000).

### 4.4. Absorbed Dose Rate

This was achieved using Equation 4. The result of absorbed dose rate for soil is in Tables 2 and 3. The maximum and minimum values obtained are 45.73 $nGyh^{-1}$ and 30.33 $nGyh^{-1}$ from corn (55.58 $nGyh^{-1}$ and 29.52 $nGyh^{-1}$ from soil) respectively. the absorbed dose rates are still lower than the world permissible value of 55 $nGyh^{-1}$ (UNSCEAR, 2000).

### 4.5. Annual Effective Dose Rate (AEDR) and Excess Lifetime Cancer Risk

Both annual effective dose rate and excess lifetime cancer risk were determined by employing Equations 5 and 6 correspondingly. Table 2 presents the results from corn samples; Table 3 displays those of soil. From corn, the maximum values from annual effective dose rate and excess lifetime cancer risk are 0.06 $mSvy^{-1}$ and $0.20\times10^{-3}$; the minimum values are 0.04 $mSvy^{-1}$ and $0.13\times10^{-3}$ respectively. From soil, the maximum values 0.07 06 $mSvy^{-1}$ and $0.24\times10^{-3}$; the minimum values are 0.0406 $mSvy^{-1}$ and $0.13 \times10^{-3}$ respectively. Consumption of corn in these areas is not harmful as the values were below the world permissible limit of $0.29\times10^{-3}$.

## 5. Conclusion

Farmers cultivate the soil and plant food crops which makes them come in direct contact with the soil. Evaluating the radiological risk associated with the inhalation of this soil by farmers was very important. The radiological health risk due to consumption of corn as well as due to inhalation of soil by the farmers have been assessed. The results of radium equivalent, absorbed dose rate, annual effective dose as well as excess lifetime cancer risk due noted from soil is higher than the results obtained from the consumption of corn. The mean activity concentrations of the radionuclides determined from both sources are lower than the world average standards; it is relatively safe to plant and consume corn planted in the areas of study. It is important to educate farmers on best agricultural practices so as to reduce the activity concentration levels introduced to the soil. These include the type and quantity of fertilizers to be used during cultivation and the fact that every farmer should wear nose mask to reduce exposure to radiation such as alpha radiations. The radium equivalent noted in the study is insignificant when compared to the world average. The high transfer factor may show high ability to transfer radionuclides in the soil to corn but from the activity evidence, these radionuclides are low as well as annual effective doses. The lifetime cancer risks due to the ingestion were also lower than that of the world average limit of $1.0\text{x}10^{-3}BqKg^{-1}$.

## Compliance with ethical standards

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*Disclosure of conflict of interest*

No potential conflict of interest.

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