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# Activity concentration, transfer factor and radiological health risk assessment of natural radionuclides in soil and maize in oil producing areas in Akwa Ibom state, Nigeria

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## Abstract

The activity concentration (AC) of $^{238}U$, $^{232}Th$, $^{40}K$ of soil and maize in oil producing areas has been studied. Also studied are the transfer factor (TF) from soil to maize and the radiological health risk associated with consumption of maize. The equipment used was the Sodium Iodide-Thallium (NaI(TI)) detector. The mean activity concentration (AC) (Bqkg$^{-1}$) of $^{238}U$, $^{232}Th$, $^{40}K$ in soil are 12.77±0.25, 41.36±0.70 and 458.61±8.04 while that of maize are 14.36±0.27, 19.23±0.46 and 425.25±7.87 respectively. Transfer factor (TF) from soil to maize of $^{238}U$, $^{232}Th$ and $^{40}K$ are 1.14, 0.50 and 0.94 correspondingly. Other useful results obtained in this research include the Radium Equivalent (Raeq), Absorbed Dose Rate (ADR), Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR) as 74.59 Bq/kg, 37.14 nGy/h, 0.05 mSv/y and 0.16 respectively. The average values of soil activity concentration from the oil producing areas are within world permissible limits given by UNSCEAR (2000) as 420 Bqkg$^{-1}$ for $^{40}K$, 33 Bqkg$^{-1}$ for $^{238}U$ and 45 Bqkg$^{-1}$ for $^{232}Th$. However, $^{238}U$ and $^{232}Th$ from maize activity concentration are far higher than world permissible limits of 0.02 Bqkg$^{-1}$ and 0.003 Bqkg$^{-1}$ respectively. The mean value of the radiological hazard indices was below the WMPV given as 370 Bq/kg for Raeq, 59 nGy/h for ADR, 1 mSv/y for AED and $0.29\times10^{-3}$ for ELCR. This clearly shows that radiation doses exposed to Akwa Ibomites through the consumption of maize cultivated in this area poses very little to no effect to their health as only about 16 out of every 100,000 persons may likely have cancer fatality in their time.

**Keywords:** Soil; Maize; Activity Concentration; Transfer Factors; Radionuclides; Excess Lifetime Cancer Risk

## 1 Introduction

Soil and crops present a direct pathway in which human and animal are exposed to natural radiations either by absorption, ingestion or inhalation. Exposure to high dose of ionizing radiation whether natural or artificial calls for concerns because of its consequences. These radionuclides including $^{238}U$, $^{232}Th$, $^{40}K$ exist in our environment since the earth was formed which may be important in the yield of our planet ecosystems. Atat et al. (2017) confirms this; soil is one of its major sources (Yarima et al., 2019). The biological as well as the chemical component of the soil, can be taken in by living organism either directly by inhalation or absorbed by the skin or indirectly, by contaminating the food and crop that is cultivated in it. The average annual exposure to the public due to natural ionizing sources of radiation is estimated to be about 0.4 mSvy-1 with possible values ranging from 1 - 5 mSvy-1 worldwide (Jibiri, 2006). According to the reported epidemiological and laboratory studies, uranium primarily induces health problems by the production of toxic effects on the reproductive organs among others which include the nervous system, lungs, genital organs, liver, bones as well as the kidney (Ma et al., 2020). Individuals exposed to thorium, also have an increased risk of bone cancer

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because thorium may be stored in bone (NCI, 2022). Even plants are affected by high radionuclide presence in soil as high potassium concentrations in the soil solution inhibit magnesium (Mg) uptake and may induce Mg deficiency in plants (Trankner et al., 2018; Xu et al., 2020).

Maize scientifically called Zea mays L. (Revilla et al., 2022) is a staple food crop which is widely consumed over the world by all ages. It is the most abundantly produced cereal in the world and grown in every continent except Antarctica (IITA, 2023). However, this important source of carbohydrate, fiber, vitamins and minerals could pose a threat to human consumption because of the high level of contamination of radioactive materials.

This work, apart from determining the activity concentration of these radionuclides, will also assess the health risks associated with their consumption and transfer factor from soil to maize seeds in oil producing areas of Akwa State. Health is wealth and the measurement technique adequate is Sodium Iodide-Thallium Gamma Spectroscopy (Rahim et al., 2019).

## 2 Material and methods

### 2.1. Location of the Study Area

Akwa Ibom State is one of the states in the south-south geopolitical zone of Nigeria and situated in the southern coastal region of the country, bordering the Atlantic Ocean with Nigeria. Local government areas in the southern part of the state have large deposits of crude oil and gas both on and offshore (AKSG, 2012). This makes the state, one of the oil producing states in the Niger Delta, Nigeria. Niger Delta lies within latitudes $3^0$N and $6^0$N; longitudes $5^0$E and $8^0$E. This fact is documented in Akpabio et al. (2023), Atat et al. (2020a), Atat et al. (2020b) and other scientific publications have confirmed it. The local government areas that have crude oil in explorable quantities make up these oil producing areas. They include Eastern Obolo, Eket, Esit Eket, Ibeno, Ikot Abasi, Mbo, Mkpat Enin and Onna (Figure 1). This area lies between 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 (Benjamin et al., 2022; Eyibio et al., 2023). Mobil Producing Nigeria Unlimited, Elf and Addax are some of the companies exploring oil in that area. The information on the two seasons in the region by Atat and Umoren (2016), Atat et al. (2020b) indicates that the region experiences both the rainy (wet) season which is from March to October and dry season (from November to February) as well.

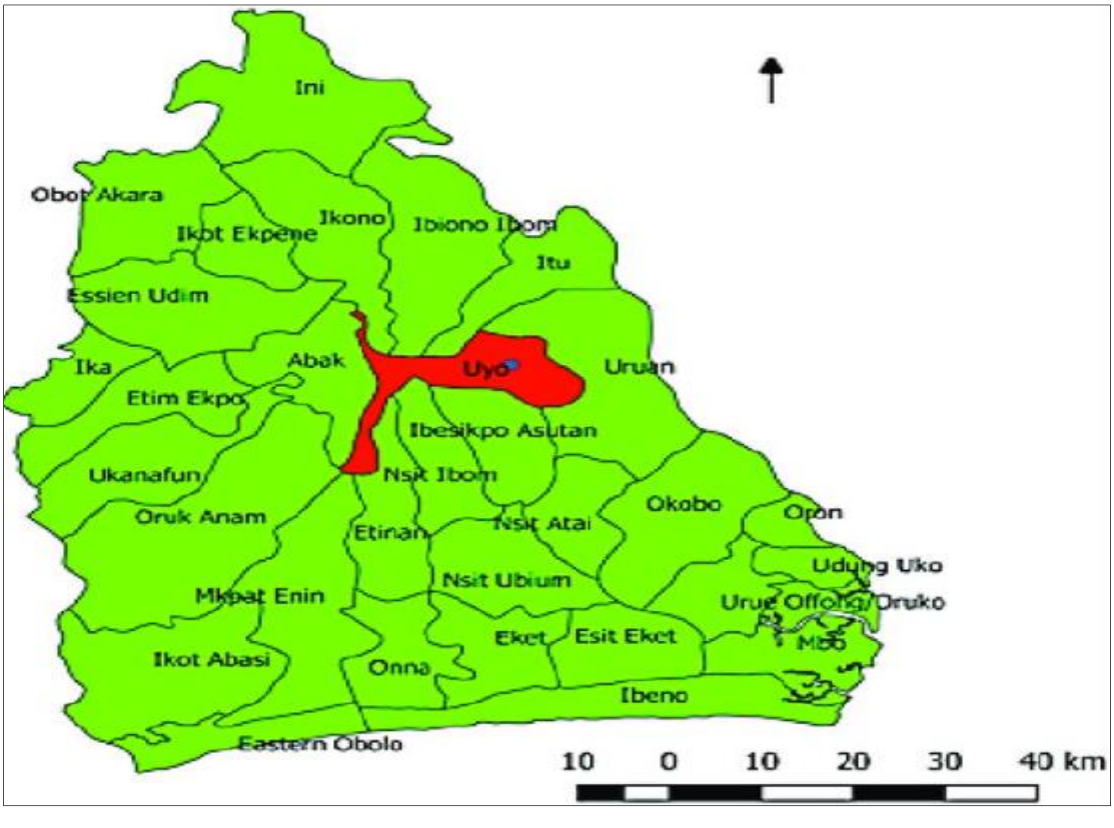


**Figure 1** Map highlighting the study area (Bello et al., 2023)

### 2.2. Sample Collection, Preparation and Analysis

Ten maize and soil samples were randomly collected from both subsistence and commercial farm lands in the study area. Adequate spread was considered in the selection of these sampling sites. Random sampling technique was employed to achieve statistical sensitivity of samples (IAEA, 2023). At each sampling site, after due consent was taken, two maize ears were harvested and immediately put into a black nylon bag. A masking tape was used to wrap the bag and the site name and location was written on the masking tape to clearly identify the sample. The soil at the root of the plant that hosted the maize seeds was cleared to remove weed, debris, stone, roots, leaves and every other thing that was not soil (Essien et al., 2017). 2 kg of soil was then taken with a trowel at the depth of 25 to 30 cm. The soil was immediately put into a black polythene bag to ensure that the radon gas did not escape from the soil sample collected Essiett et al., 2022). The maize was dehusked and the silk was removed, plucked out of the kernel, and sundried. The maize samples were vigorously mixed per local government area to obtain the average for each local government. They were grinded and sieved through a 1mm sieve to obtain very fine powder. The maize powder was further dried up to completely eliminate any moisture content in an oven at about 1100C for 1 hour. The soil samples were air dried, ground, sieved, packed, sealed and labelled appropriately. The soil and maize seeds samples were properly bagged and sent to the Center for Energy Research and Development, Obafemi Awolowo University Ile-Ife for measurement of $^{238}$U, $^{232}$Th, $^{40}$K using a Sodium Iodide-Thalium (NaI (TI)) detector.

### 2.3. Radioactivity Concentration in soil and maize

The estimation of the radioactivity concentration of the radionuclides per unit mass may be carried out using the Equation 1 (Essien et al., 2021; Eyibio et al., 2023).

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

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

### 2.4. Transfer Factor

Transfer factor which determines the potential for radionuclides to be transferred from one environmental compartment to another such as soil to plants is a dimensionless quantity and given by the Equation 2 (Eyibio et al., 2023).

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

Where $C_P$ is the concentration of radionuclides in plant (maize) while $C_S$ is the concentration of the same radionuclide in soil within the rooting zone of the plant.

### 2.5. Radium Equivalent Activity

This is a singular value representing all radionuclides present in a material that emits equivalent gamma dosage as $^{226}$Ra (Radium-226) and its decay products. It may be determined using Equation 3 and expressed in units of Becquerel per kilogram ($Bqkg^{-1}$).

$$a_{eq} = C_U + 1.43C_{Th} + 0.077C_K \text{...............} \ (3)$$

Where $C_U$, $C_{Th}$, $C_K$ are the average concentration of $^{238}$U, $^{232}$Th, $^{40}$K respectively.

### 2.6. Absorbed Dose Rate in Air

Absorbed dose rate in air is the dose received by a person from radioactive materials in the environment when outside and was calculated at a height of 1 meter above the ground level from the measured activity concentration of $^{238}$U, $^{232}$Th and $^{40}$K radionuclides as shown in Equation 4.

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

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

### 2.7. Annual Effective Dose

Annual effective dose was calculated to evaluate the health effects of the absorbed dose (UNSCEAR, 1993) using the conversion coefficient of 0.7SvG/y to transform absorbed dose in air to the effective dose received by human beings. 0.2 outdoor occupancy factor may be used (people spend an average of 20% of their time outdoors) (UNSCEAR, 1993). The equation for the calculation of the annual effective dose is therefore given by (Essien et al., 2017) as shown in Equation 5

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

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.

### 2.8. External and Internal Hazard Index

External hazard index is the potential radiation dose received by an individual from gamma radiation emitted from natural radionuclides ($^{238}U$, $^{232}Th$ and $^{40}K$) in the environment and is given by

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \ldots\ldots\ldots\ldots\ldots (6)$$

Internal hazard index is the potential radiation dose received by an individual from the inhalation of natural occurring radionuclides ($^{238}U$, $^{232}Th$ and $^{40}K$) present in the environment and is given by

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where $C_U$, $C_{Th}$, $C_K$ are the activity concentrations of $^{238}U$, $^{232}Th$, $^{40}K$ respectively.

### 2.9. Gamma Index

Otherwise known as radioactivity level index is used to determine the gamma radiation hazard associated with the natural radionuclide in a particular sample that is being investigated. It is given by (Bede et al., 2015) as seen in Equation 8.

$$I\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where $C_U$, $C_{Th}$, $C_K$ are the corresponding activity concentrations of $^{238}U$, $^{232}Th$, $^{40}K$.

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

The excess lifetime cancer risk is a term that is used to calculate the potential carcinogenic effects that the members of the public may likely be exposed to if they consume maize for a long time. The excess lifetime cancer risk associated with the consumption of maize seeds was calculated using Equation 9.

$$ELCR = AED \times RF \times DL \ldots\ldots\ldots\ldots (9)$$

Where AED is annual effective dose due to consumption of food crops (maize seeds), 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 Results and discussion

### 3.1. Radionuclide activity concentration

The activity concentration of soil and maize was determined for all local government areas in the oil producing area as reported in Table 1. Onna has the highest activity concentration of soil in $^{238}U$ and $^{232}Th$ as 14.64±0.27 and 59.57±1.00 $Bqkg^{-1}$ respectively while highest soil activity concentration for $^{40}K$ was from Ibeno and given as 552.68±7.33 $Bqkg^{-1}$. From maize, Ikot Abasi has the highest activity concentration in $^{238}U$ and $^{40}K$ which are 15.58±0.28 and 15.58±0.28 $Bqkg^{-1}$ respectively; Eastern Obolo has the highest maize activity concentration in $^{232}Th$ as 25.98±0.66 $Bqkg^{-1}$. Five out of the eight oil producing local government areas have values of soil $^{40}K$ higher than the world permissible limit of 420 $Bqkg^{-1}$ according to (UNSCEAR, 2000); two local government areas have higher values of soil $^{232}Th$ higher than the world permissible limits. The activity concentrations of $^{238}U$ and $^{232}Th$ in maize are above the world permissible limit.

**Table 1** Activity concentration in soil and maize samples for oil producing areas

| **LGA** | **SOIL** | | | **MAIZE** | | |
|---|---|---|---|---|---|---|
| **LGA averages** | **K-40 ($Bqkg^{-1}$)** | **U-238 ($Bqkg^{-1}$)** | **Th-232 ($Bqkg^{-1}$)** | **K-40 ($Bqkg^{-1}$)** | **U-238 ($Bqkg^{-1}$)** | **Th-232 ($Bqkg^{-1}$)** |
| Eastern Obolo | 410.06±7.79 | 13.37±0.26 | 58.77±0.99 | 473.37±8.37 | 14.92±0.28 | 25.98±0.66 |
| Eket | 509.74±8.97 | 13.03±0.25 | 40.11±0.38 | 384.85±7.45 | 12.78±0.26 | 23.05±0.26 |
| Esit Eket | 521.74±8.79 | 11.33±0.24 | 40.84±0.83 | 411.83±7.81 | 13.17±0.26 | 20.09±0.58 |
| Ibeno | 552.68±7.33 | 12.88±0.24 | 39.72±0.26 | 444.52±8.11 | 14.02±0.27 | 20.04±0.58 |
| Ikot Abasi | 436.83±8.04 | 13.89±0.27 | 24.30±0.64 | 631.65±9.67 | 15.58±0.28 | 24.15±0.64 |
| Mbo | 472.92±8.36 | 12.92±0.26 | 40.29±0.82 | 421.44±7.90 | 13.34±0.26 | 18.04±0.55 |
| Mkpat Enin | 354.88±7.25 | 10.10±0.23 | 27.31±0.68 | 379.43±7.49 | 15.49±0.28 | 9.94±0.41 |
| Onna | 410.06±7.79 | 14.64±0.27 | 59.57±1.00 | 254.88±6.14 | 15.56±0.28 | 12.51±0.46 |
| Average | 458.61±8.04 | 12.77±0.25 | 41.36±0.70 | 425.25±7.87 | 14.36±0.27 | 19.23±0.46 |
| Permissible maximum value (UNSCEAR,2000) | 420 | 33 | 45 | - | 0.02 | 0.003 |

**Table 2** Soil Activity concentration comparison with other local government areas in other works

| **Location** | **$^{238}U$** | **$^{232}Th$** | **$^{40}K$** | **Source** |
|---|---|---|---|---|
| Eastern Obolo | 13.37±0.26 | 58.77±0.99 | 410.06±7.79 | This study |
| Eket | 13.03±0.25 | 40.11±0.38 | 509.74±8.97 | This study |
| Esit Eket | 11.33±0.24 | 40.84±0.83 | 521.74±8.79 | This study |
| Ibeno | 12.88±0.24 | 39.72±0.26 | 552.68±7.33 | This study |
| Ikot Abasi | 13.89±0.27 | 24.30±0.64 | 436.83±8.04 | This study |
| Mbo | 12.92±0.26 | 40.29±0.82 | 472.92±8.36 | This study |
| Mkpat Enin | 10.10±0.23 | 27.31±0.68 | 354.88±7.25 | This study |
| Onna | 14.64±0.27 | 59.57±1.00 | 410.06±7.79 | This study |
| Obot Akara | 45.32±2.66 | 31.14±1.63 | 129.32±6.84 | (Essiett et al., 2022) |
| Oruk Anam | 33.65±1.95 | 21.28±1.13 | 2.35±0.26 | (Essiett et al., 2022) |
| Essien Udim | 82.98±4.39 | 61.02±3.21 | 50.85±2.71 | (Essiett et al., 2022) |
| Etim Ekpo | 53.33±2.95 | 50.40±2.66 | 35.67±1.93 | (Essiett et al., 2022) |
| Ikono | 89.10±4.71 | 68.42±3.61 | 18.74±1.13 | (Essiett et al., 2022) |
| Ini, | 4.44 ± 1.05 | 9.12 ± 0.89 | 105.39 ± 7.56 | (Akankpo et al., 2021) |
| Ikot Ekpene | 48.60±0.99 | 7.38±0.84 | 96.36±7.12 | (Essien et al., 2021) |
| Itu | 2.47 ± 0.26 | 3.70 ± 0.22 | 143.54 ± 7.56 | (Essien and Akpankpo, 2017) |
| Ibiono Ibom | 8.26 ± 2.06 | 9.13 ± 1.03 | 238.10 ±22.47 | (Essien et al., 2017) |
| Uyo | 12.13 ±1.98 | 19.09 ± 0.71 | 67. 37 ± 3.29 | (Essien and Akpankpo, 2017) |
| Abak | 24.83±5.43 | 5.172±0.31 | 98.71±7.70 | (Chad-Umoren et al., 2014) |

Soil activity concentration of the local government areas in the oil producing area of Akwa Ibom State was compared to results from other local government areas in other studies as shown in Table 2. While results from this study had higher $^{40}$K values, than all the local government areas it was compared to $^{238}$U and $^{232}$Th was different. Itu, Ini and Ibiono had lower values of $^{238}$U than the present study, Uyo had comparable values while Obot Akara, Oruk Anam, Essien Udim, Etim Ekpo, Ikono and Ikot Ekpene had very high values even higher than the world recommended value of 33 Bqkg$^{-1}$. $^{232}$Th activity concentration from other works were either lower or comparable to the present study. The maize activity concentration of the local government in the oil producing areas could not be compared to that of other local government areas in Akwa Ibom state because of paucity of data as searches in the literature does not present any work on activity concentration of maize in any part of the State.

**Table 3** Calculated radiological hazards for the maize samples for oil producing areas

| **LGA averages** | **Raeq (Bqkg$^{-1}$)** | **$D\gamma$ (nGyh$^{-1}$)** | **AED (mSvy$^{-1}$)** | **($H_{ex}$)** | **($H_{in}$)** | **($I_\gamma$)** | **ELCR (×10$^{-3}$)** |
|---|---|---|---|---|---|---|---|
| Eastern Obolo | 88.52 | 43.92 | 0.05 | 0.24 | 0.28 | 0.67 | 0.19 |
| Eket | 75.37 | 37.26 | 0.05 | 0.20 | 0.24 | 0.57 | 0.16 |
| Esit Eket | 73.61 | 36.63 | 0.04 | 0.20 | 0.23 | 0.56 | 0.16 |
| Ibeno | 76.91 | 38.37 | 0.05 | 0.21 | 0.25 | 0.59 | 0.16 |
| Ikot Abasi | 98.75 | 49.80 | 0.06 | 0.27 | 0.31 | 0.77 | 0.21 |
| Mbo | 71.59 | 35.76 | 0.04 | 0.19 | 0.23 | 0.55 | 0.15 |
| Mkpat Enin | 58.92 | 29.51 | 0.04 | 0.16 | 0.20 | 0.46 | 0.13 |
| Onna | 53.08 | 25.89 | 0.03 | 0.14 | 0.19 | 0.40 | 0.11 |
| Average | 74.59 | 37.14 | 0.05 | 0.20 | 0.24 | 0.57 | 0.16 |
| World Permissible limit | 370 | 55 | 1 | 1 | 1 | 1 | 0.29 |

**Table 4** Soil to maize transfer factor for oil producing areas in Akwa Ibom State

| **LGA** | **TF $^{238}$U** | **TF $^{232}$Th** | **TF $^{40}$K** |
|---|---|---|---|
| Eastern Obolo | 1.12 | 0.44 | 1.15 |
| Eket | 0.98 | 0.57 | 0.75 |
| Esit Eket | 1.16 | 0.49 | 0.79 |
| Ibeno | 1.09 | 0.50 | 0.80 |
| Ikot Abasi | 1.12 | 0.99 | 1.45 |
| Mbo | 1.03 | 0.45 | 0.89 |
| Mkpat Enin | 1.53 | 0.36 | 1.07 |
| Onna | 1.06 | 0.21 | 0.62 |
| Average | 1.14 | 0.50 | 0.94 |

The radiological health risk associated with consumption of maize from this area was calculated using parameters including the Radium Equivalent (Raeq), Absorbed Dose Rate in Air (Dγ), Annual Effective Dose (AED), External and Internal Hazard Indices, Gamma index and Excess Lifetime Cancer Risk and the result is as shown in Table 3. The transfer factor was also computed and the result are shown in Table 4.

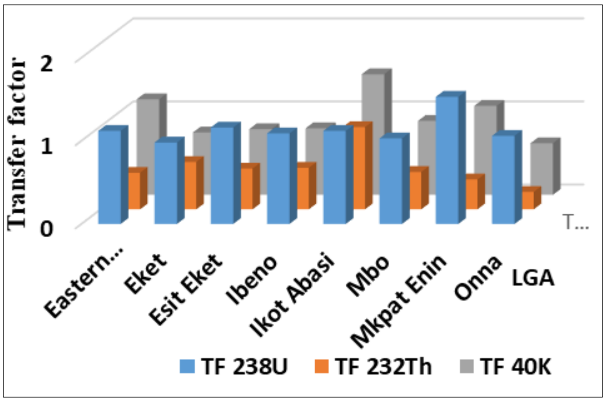


**Figure 2** Transfer Factor Distribution of the three Radionuclides for each LGA

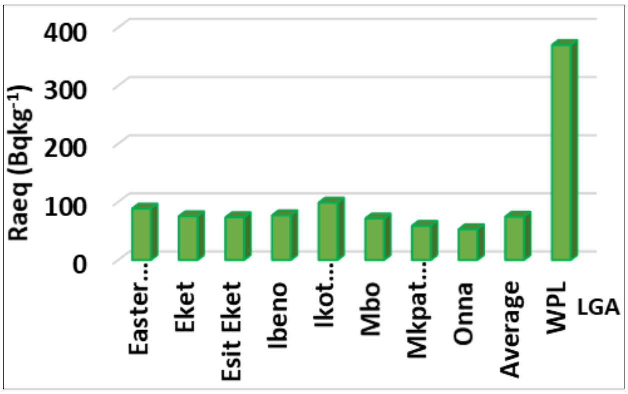


**Figure 3** Radium Equivalent (Raeq) Distribution for each LGA

### 3.2. Transfer Factor of Radionuclides from Soil to Maize

Transfer factors from soil to maize of the three radionuclides under investigation in this work was obtained as seen in Figure 2. $^{238}$U had values ranging from 0.98 to 1.53 with mean of 1.14, $^{232}$Th had values ranging from 0.21 to 0.99 with mean of 0.50, $^{40}$K had values ranging from 0.62 to 1.45 with mean of 0.94. The mean highest transfer factors for the different radionuclides were from $^{238}$U while the lowest was from $^{232}$Th. This may be linked to the fact that Uranium is more mobile than Thorium. $^{238}$U had values slightly higher than unity which is its world maximum permissible value. $^{232}$Th and $^{40}$K had values lower than the world permissible value for them which is given as 1 and 5.60 respectively.

### 3.3. Radium Equivalent

Figure 3 shows that the highest mean value for the $Ra_{eq}$ in the oil producing area in Akwa Ibom State was obtained from Ikot Abasi as 98.75 Bqkg$^{-1}$ while the lowest was obtained in Onna local government area as 53.08 Bqkg$^{-1}$. However, the Raeq in all the local government areas in the oil producing area of Akwa Ibom State was far lower than the world permissible limits of 370 Bqkg$^{-1}$.

### 3.4. Absorbed Dose Rate

The absorbed dose rate ranged from 25.89 nGyh$^{-1}$ – 49.80 nGyh$^{-1}$. The trend of Ikot Abasi having the highest value and Onna having the lowest value was also seen in the computation of the Absorbed Dose Rate in Air in Figure 4. Though the margin of the values to the world maximum permissible limits was not as high as that of the Raeq, the absorbed dose rate in air was still lower than the world permissible value of 55 nGyh$^{-1}$.

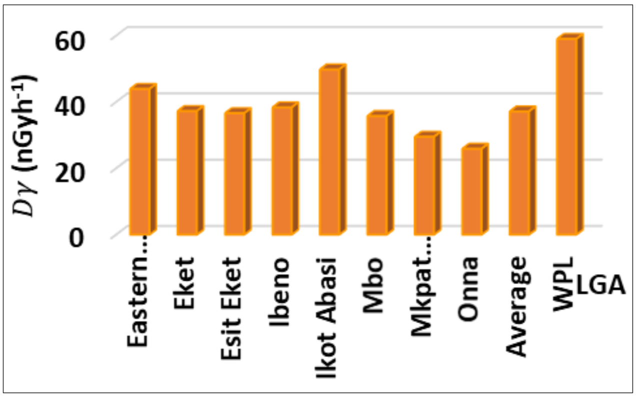


**Figure 4** Absorbed Dose Rate in Air (Dγ) Distribution for each LGA

### 3.5. Other Radiological Hazard Indices

Figure 5 shows the computed results for annual effective dose rate (AEDR), external and internal hazard indices (Hex, Hin) and gamma index (Iγ) distribution for each LGA. The Annual Effective Dose ranged from 0.3 $mSvy^{-1}$ to 0.6 $mSvy^{-1}$ with mean value of 0.05 $mSvy^{-1}$. External hazard index had values ranging from 0.14 $Bqkg^{-1}$ to 0.27 Bqkg-1 with a mean value of 0.20 $Bqkg^{-1}$.

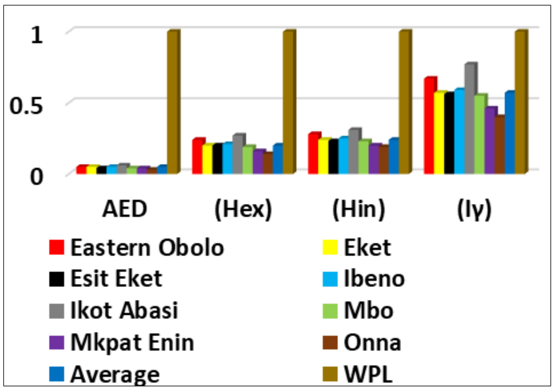


**Figure 5** Annual Effective Dose Rate (AEDR), External Hazard index ($H_{ex}$) and Internal Hazard Index ($H_{in}$) and Gamma Index (Iγ) Distribution for each LGA

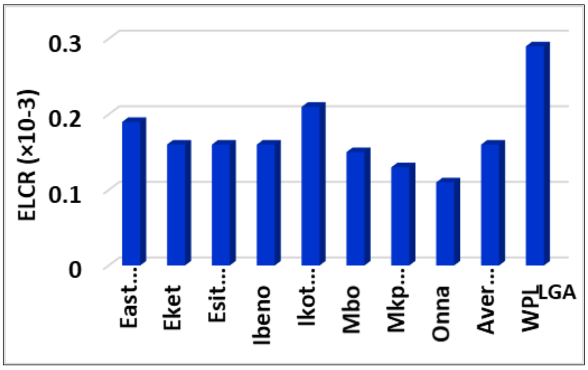


**Figure 6** Excess Lifetime Cancer Risk (ELCR) Distribution for each LGA

Internal hazard index had values ranging from 0.19 $Bqkg^{-1}$ to 0.31 $Bqkg^{-1}$ with a mean value of 0.24 $Bqkg^{-1}$. Gamma index had values ranging from 0.40 $Bqkg^{-1}$ to 0.77 $Bqkg^{-1}$ with a mean value of 0.53 $Bqkg^{-1.}$ As seen earlier in other radiological hazard indices, Ikot Abasi still has the highest values for all the parameters while Onna has the lowest values for all the parameters under consideration. All these local government areas have results far lower than unity which is their permissible limits for the parameters under consideration.

### 3.6. Excess lifetime cancer risk

The Excess lifetime cancer risk mean value for the area is shown in Figure 6 as $0.16 \times 10^{-3}$ and the area have values ranging from $0.11 \times 10^{-3}$ to $0.21 \times 10^{-3}$. This translates to the fact that 11 to 21 out of every 100000 persons are likely to come down with cancer fatality for a period of 70 years. These values are below world permissible limit of $0.29 \times 10^{-3}$.

## 4 Conclusion

Activity concentration of radionuclides in this area of study was determined and the transfer factors and radiological hazards due to consumption of maize was computed. $^{40}K$ was found to be the most abundant radionuclide amongst the three radionuclides investigated in this study. This could be linked to the fact that this radionuclide is essential for plant growth and thus it is present in fertilizers added to boost plant growth. The study reveals that the Radium equivalent was far lower than 370 $Bqkg^{-1}$, Annual effective dose rate was lower than 1 $mSvy^{-1}$ other radiological risk factors including External, Internal and Gamma indices were all far below unity which is the world permissible maximum values. Most importantly, the mean excess lifetime cancer risk for the area was $0.16 \times 10^{-3}$ which is below the world recommended value of $0.29 \times 10^{-3}$. This clearly shows that radiation doses noted through consumption of maize cultivated in this area poses very little to no effect to their health.

## Compliance with ethical standards

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No conflict of interest to be disclosed.

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