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Investigation of the Transfer Influence and Health Threat from the Intake of Maize and Exposure to Soil in Different Geological Formations in Akwa Ibom State, Nigeria

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ABSTRACT

The consumption of maize contaminated by radionuclides may pose certain health challenges to the body. This research was conducted to investigate the possible danger radionuclides could cause. Soil and maize samples were obtained from different geological formations. They were analyzed using a Sodium Iodide-Thalium (NaI(TI)) detector. The activity concentration results from the soil samples show the highest values of ^{238}U, ^{232}Th and ^{40}K as 14.74±0.26 Bqkg^{-1}, 40.34±0.73 Bqkg^{-1} and 444.89±8.12 Bqkg^{-1} respectively which correspond to Ogwashi-Asaba, Ogwashi-Asaba and Imo shale geological formations. The findings from maize samples indicate the maximum values of ^{238}U, ^{232}Th and ^{40}K as 16.46±0.25 Bqkg^{-1}, 18.12±0.46 Bqkg^{-1} and 435.17±7.89 Bqkg^{-1} respectively which correspond to Benin, Ogwashi-Asaba and Ogwashi-Asaba geological formations. The outcome of mean transfer factor of ^{238}U, ^{232}Th and ^{40}K corresponds to 0.942, 0.460 and 1.002. The absorbed dose rate ranges from 28.91 nGyh^{-1} to 36.08 nGyh^{-1}. Radium equivalent varies from 49.40 Bqkg^{-1} to 98.75 Bqkg^{-1}. Almost equal value (0.15×10^{-3}) was assessed for the mean excess lifetime cancer risk. Although the activity concentration noted from maize is high, the evidence obtained shows that there is no geological formation with health risk problem as the external, internal and radioactivity hazard indices are less than unity.

Keywords:
Transfer Influence,
Health Threat,
Maize,
Radionuclides.

INTRODUCTION

Maize (Zea mays L.) is an important annual cereal crop of the world belonging to family Poaceae. Zea is an ancient Greek word which means "sustaining life" and Mays is a word from Taino language meaning "life giver. It is a source of nutrition as well as phytochemical compounds. Phytochemicals play an important role in preventing chronic diseases (Shah et al., 2016). It possesses vital nutrients, minerals and vitamins, which provides nutrition in animal diet as well as man (Adiaha, 2017).

Soil is a biologically active porous medium that has developed in the uppermost layer of Earth's crust. Soil is a mixture of minerals and organic material that covers much of Earth's surface. It is not as solid as rock and has many small spaces called pores that hold water and air. It is also a non-renewable dynamic natural resource that is essential to life. Water movement, water quality, land use, and vegetation productivity all have relationships with soil (Schoonover and Crim, 2015).

The soil to plant (maize) transfer factor is a measure of transport of radionuclides from soil to plant (Benjamin et al., 2022). Radionuclides may be introduced into the soil (which may be important in the yield of our planet ecosystems (Atat et al., 2017)), through addition of chemical fertilizers which contain heavy metals and radioactive elements such as Uranium, Thorium and their daughters (Mortvedt and Sikora, 1992), pesticides and herbicides to the soil (Eyibio et al., 2023). Akankpo et al. (2021), Essien et al. (2021), Ejoh et al. (2023) and Benjamin et al. (2022) are scientists who conducted researches on transfer factors.

The aim of this research is to assess the level of activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil which could be transferred to maize as intake item for energy building in the body. Sodium Iodide-Thalium (NaI(TI)) with High Purity Germanium (HPGe) detectors is the major equipment used for the study. The health risk associated with the consumption of maize and inhalation of soil will be known.

Location and Geology of the Study Area

Akwa Ibom State is located in the south-south part of Nigeria. It lies between latitudes $4^0\ 32^1$ and $5^0\ 33^1$ N and longitudes $7^0\ 25^1$ and $8^0\ 25^1$ E (AKSG Online, 2012; Benjamin et al., 2022). It is one of the states in the Niger Delta region. According to Atat et al. (2020a) and Atat et al. (2020b), Niger Delta lies between latitudes 3^0N and 6^0N; longitudes 5^0E and 8^0E. The Niger Delta region is categorized by two separate seasons: the rainy or wet and dry (Atat and Umoren, 2016; Atat et al., 2020b). Atat et al. (2020c) and some other researchers have noted that the average rain in a month throughout wet season is around 135 mm and falls to 65 mm when dry season is experienced. About five major geological formations are visible in Akwa Ibom State. These formations include Benin (also called the coastal plain sands), Alluvium, Ogwashi-Asaba, Ameki and Imo Shale.

Benin formation is a significant geological unit found in the Niger Delta basin which stretches along through the western part of the Niger Delta to the south coastlines (Uko *et al*., 2022). It covers about 59.8% the State total surface area (Ekpo *et al.*, 2021). 25 local government areas (Abak, Essien Udim, Esit Eket, Ukanafun, Etimekpo, Nsit Ubium, Etinan, Nsit Atai, Ibesikpo, Okobo, Ika, Nsit Ibom, Oruk Anam, Oron Urue Offong Uruko, Uyo, Eket, Ikot Abasi, Mkpat Enin, Onna, Udung Uko, Ikot Ekpene, Mbo, Obot Akara and Uruan) have Benin formation overlying in them.

Alluvium is a type of sedimentary deposit that forms through the action of flowing water. It is a loose, unconsolidated material made up of a mixture of rock fragments, sand, silt, clay, shales, gravels and organic matter that has been transported and deposited by moving water (Ekpo *et al*., 2021). It covers about 20.47% of Akwa Ibom with a total surface area (Ekpo *et al*., 2021). 13 local government areas (Eastern Obolo, Ibeno, Eket, Esit Eket, Ikot Abasi, Mbo, Mkpat Enin, Okobo, Onna, Oron, Udung Uko, Uruan and Itu) have Alluvium sand.

Ogwashi-Asaba formation was once known as a lignite group (Wilson, 1925). It is a series of coarse-grained sandstone, carbonate-based shale and clay that contains intercalations of continental lignite seams (Ogala, 2012). It covers about 11.77% of Akwa Ibom with a total surface area (Ekpo et al., 2021). It is visible in Ikot Ekpene, Itu, Ikono, Ibiono Ibom, and Uruan local government areas.

Imo geological formation is the smallest formation; it is made up of fine-textured, thick, clayey shale that ranges in color from black to bluish grey. Mixed thin bands of sandstone and clay ironstone could be seen (Ikechukwu, 2017). It appears in the upper northern part of Akwa Ibom State covering an average of about 3.72% of State, (Ekpo et al., 2021). This formation is found in only two local government areas (Ibiono Ibom and Ini).

Ameki Formation is seen as a clastic material unit which is made up of limestone, siltstones, shales, sandstones, and ironstones. The Imo formation is uniformly overlain by the Ameki Group facies. They pinched out both eastwards and westwards. It appears in the upper northern part of the State in the same region as the Imo Shale formation. It covers 4.24% of Akwa Ibom State (Ekpo *et al*., 2021). Ibiono Ibom, Ini, Ikono and Itu local government areas have the presence of Ameki formation.

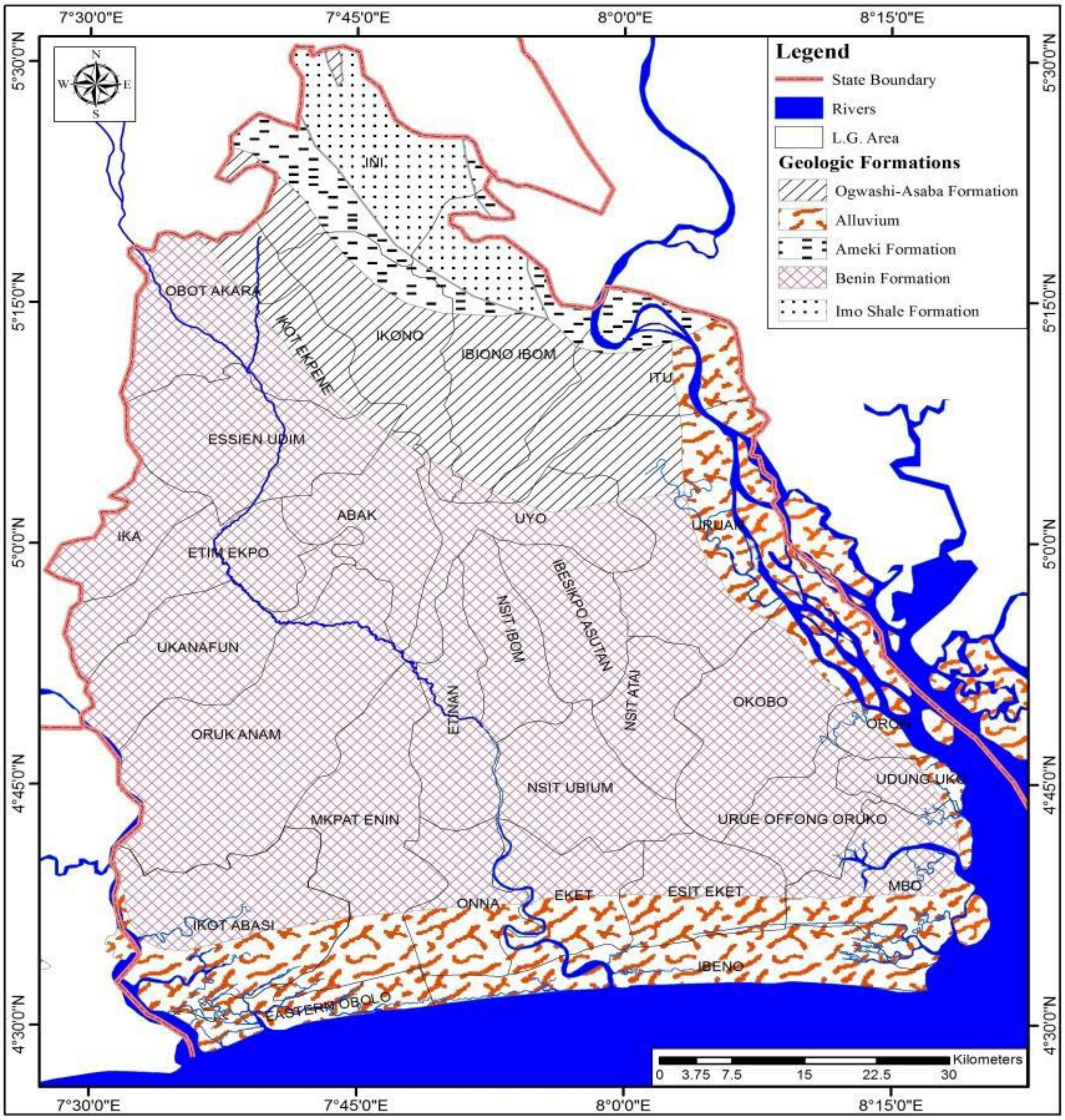

Figure 1: Geological map of Akwa Ibom State (Inim *et al.*, 2020)

MATERIALS AND METHODS

Sample Collection, Preparation and Analysis

Soil and maize samples were collected randomly (IAEA, 2010) from the geological formations in Akwa Ibom State. The weeds grown on the soil where the maize was planted was removed to ensure accuracy in findings (Essiett *et al.*, 2022). About 2kg of soil samples were collected from the depth of about 25 to 30 cm and immediately placed inside a black polythene bag (Essien *et al.*, 2021). The maize was dehusked, the silk was extracted, the seeds were detached and allowed to dry in the sun. They were ground into powdered form and then sifted through a 1 mm sieve. It was further dried in an oven set at about 110^0C for an hour. This procedure was repeated using soil samples; both prepared samples were taken to the Center for Energy Research and Development, Obafemi Awolowo University at Ile-Ife for examination. The major device used for further analysis was a Sodium Iodide-Thalium (NaI(TI)) detector.

Activity Concentration (AC) and Transfer Factor (TF)

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.

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

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

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

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

Radium Equivalent Activity (Ra_{eq}) 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.

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

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

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

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).

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

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

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.

$$\mathrm{ELCR} = \mathrm{AED} \times \mathrm{RF} \times \mathrm{DL} \qquad (6)$$

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).

External and Internal Hazard Index

The potential radiation dose received by a person from gamma (or x-) radiation or natural radionuclides (^{238}U, ^{232}Th and ^{40}K) in the environment (outside the body) is known as External hazard index. This may be determined using Equation 7. Alpha and beta particles create no external exposure hazard since they do not pass through the skin.

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (7)$$

The potential radiation dose received by an individual inside the body from radiation (radioactive material) through inhalation or eating is known as Internal hazard index. Equation 8 is adequate to determine this.

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (8)$$

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

Radioactivity Level Index (I_γ)

This is an index used to estimate the level of gamma radiation hazard connected with the natural radionuclide in a specific sample. Equation 9 is satisfactory for the assessment of this information (Essien and Akpan, 2016).

$$I_\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \qquad (9)$$

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

RESULTS AND DISCUSSION

Result

The goal of our research has been achieved with the following findings. Table 1 has the result of activity concentration from soil and maize. Table 2 and Figure 9 present the transfer factors noted in different geological formations in Akwa Ibom State due to the intake of maize planted in the soil; Figure 8 shows percentage of the radionuclide transfer contributions in the area of study. The mean computed radiological risk information is displayed in Table 3. Figures 2 to 4 reveal the percentage of concentration of ^{238}U, ^{232}Th and ^{40}K in the soil samples obtained from the geological formations respectively. Figures 5 to 7 correspondingly give the percentage of concentration of ^{238}U, ^{232}Th and ^{40}K in the maize samples. Other results obtained are absorbed dose rate from maize (Figure 10), AED (Figure 11), H_{ex} (Figure 11), H_{in} (Figure 11), I_γ (Figure 11), Ra_{eq} (Figure 12) and ELCR (Figure 13).

Table 1: Activity concentration from both samples

Formation	SOIL			MAIZE		
	K-40 ($Bqkg^{-1}$)	U-238 ($Bqkg^{-1}$)	Th-232 ($Bqkg^{-1}$)	K-40 ($Bqkg^{-1}$)	U-238 ($Bqkg^{-1}$)	Th-232 ($Bqkg^{-1}$)
Benin	404.08±7.78	13.72±0.27	37.18±0.77	430.17±8.77	16.46±0.25	12.87±0.55
Alluvium	430.17±7.56	13.89±0.24	39.29±0.63	427.49±8.24	13.47±0.28	18.04±0.62
Ogwashi-Asaba	408.28±7.96	14.74±0.26	40.34±0.73	435.17±7.89	12.52±0.26	18.12±0.46
Imo shales	444.89±8.12	14.63±0.26	38.02±0.87	369.68±7.36	11.66±0.25	12.14±0.45
Ameki	431.06±7.38	14.43±0.25	39.36±0.82	384.65±7.46	13.05±0.25	17.71±0.50
Permissible maximum value (UNSCEAR, 2000)	420	33	45	-	0.02	0.003

Table 2: Transfer factor data

Formation	TF ^{238}U	TF ^{232}Th	TF ^{40}K
Benin	1.06	0.55	1.13
Alluvium	1.00	0.53	1.02
Ogwashi-Asaba	0.89	0.46	1.11
Imo Shales	0.80	0.32	0.84
Ameki	0.96	0.44	0.91

Table 3: Mean computed radiological risk from maize samples

Formation	Raeq ($Bqkg^{-1}$)	Absorbed Dose Rate ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	External Hazard Index (H_{ex})	Internal Hazard Index (H_{in})	Gamma Index (I_{γ})	ELCR ($\times 10^{-3}$)
Benin	69.54	34.89	0.04	0.19	0.22	0.54	0.15
Alluvium	72.19	36.08	0.04	0.19	0.23	0.56	0.15
Ogwashi-Asaba	71.94	36.05	0.04	0.19	0.23	0.55	0.15
Imo Shale	57.49	28.91	0.04	0.16	0.19	0.45	0.12
Ameki	67.99	33.84	0.04	0.18	0.22	0.52	0.15

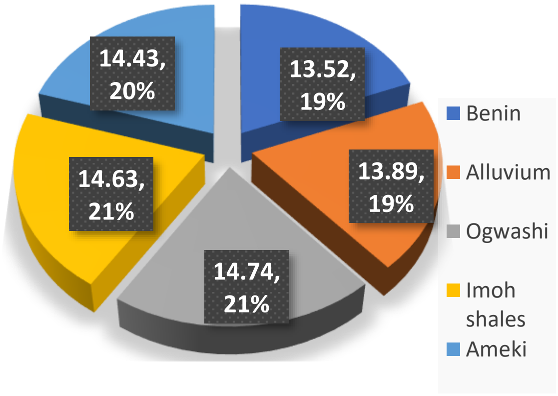

Figure 2: Activity Concentration of ^{238}U in Soil

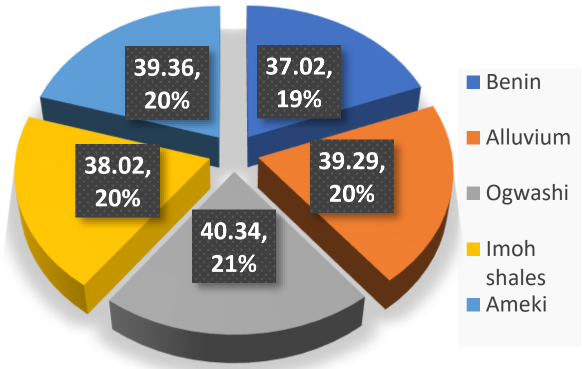

Figure 3: Activity Concentration of ^{232}Th in Soil

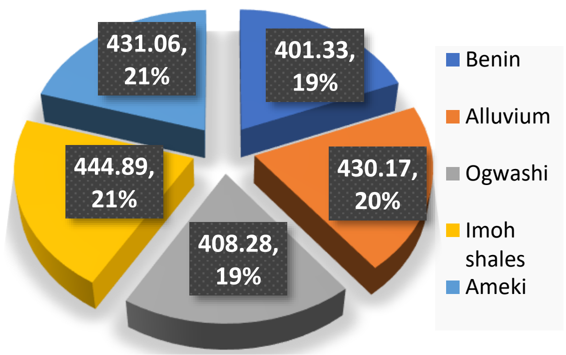

Figure 4: Activity Concentration of ^{40}K in Soil

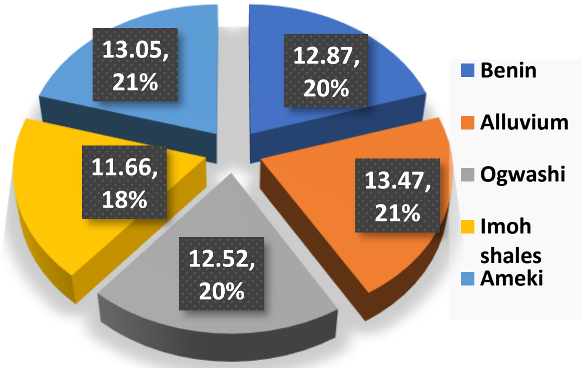

Figure 5: Activity Concentration of ^{238}U in Maize

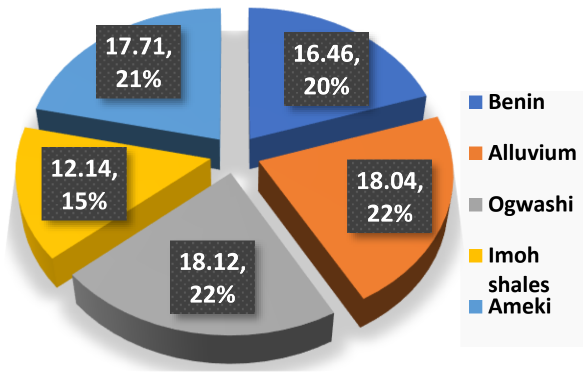

Figure 6: Activity Concentration of ^{232}Th in Maize

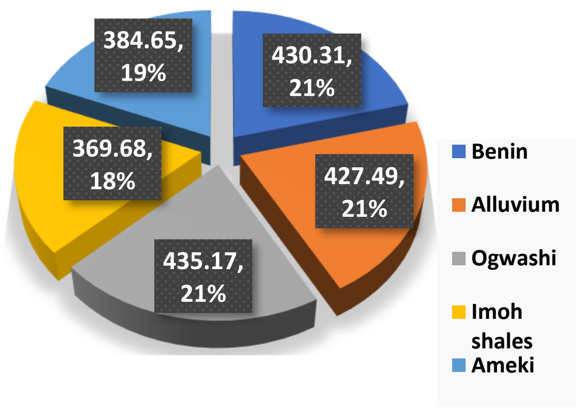

Figure 7: Activity Concentration of ^{40}K in Maize

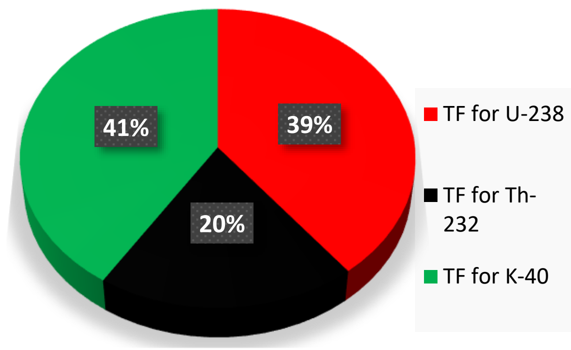

Figure 8: Transfer Factor contributions of ^{40}K, ^{232}Th, and ^{238}U in study area

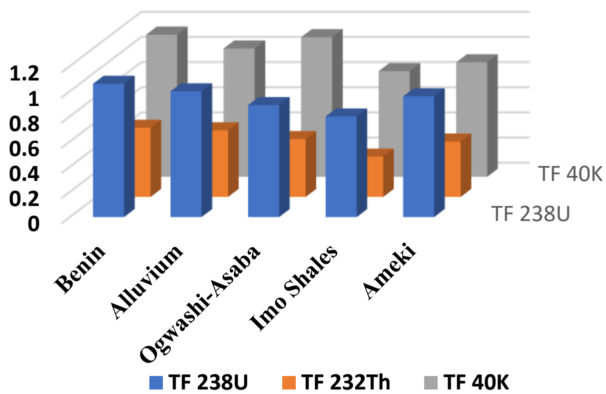

Figure 9: Transfer Factor of ^{40}K, ^{232}Th, and ^{238}U in geological formation

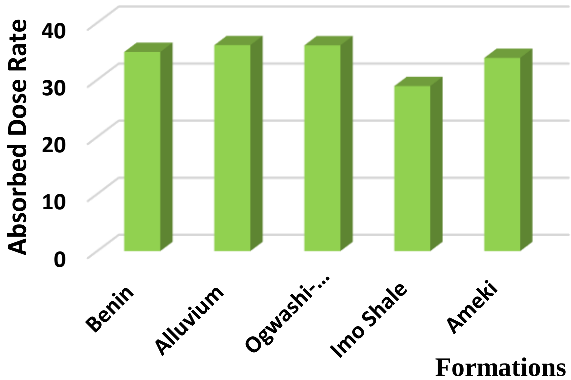

Figure 10: Absorbed dose rate due to consumption of maize

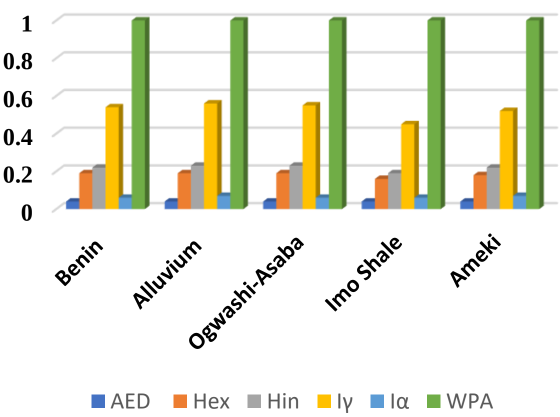

Figure 11: AED, Hex, Hin, Iγ and Iα associated with maize consumption

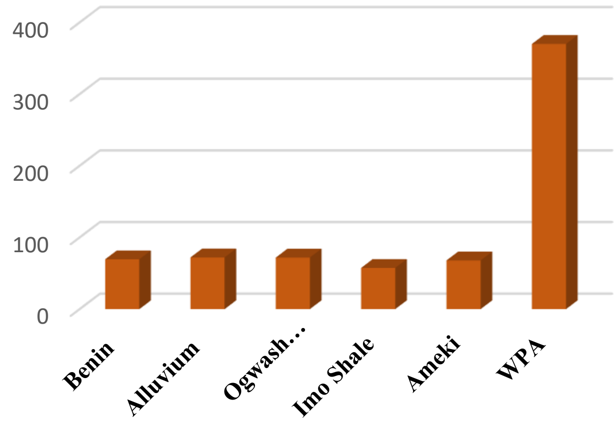

Figure 12: Ra_{eq} from maize intake

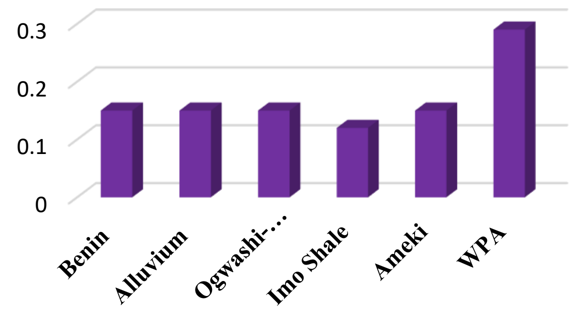

Figure 13: ELCR ($\times 10^{-3}$) outcome from the intake of maize

Discussion

Activity concentration

This was estimated using Equation 1. The outcome from soil sample is in Table 1 and Figures 2 to 4. The highest values of AC of ^{238}U, ^{232}Th and ^{40}K are 14.74±0.26 Bqkg^{-1}, 40.34±0.73 Bqkg^{-1} and 444.89±8.12 Bqkg^{-1} respectively which correspond to Ogwashi-Asaba, Ogwashi-Asaba and Imo shale geological formations. The findings from maize sample are also seen in Table 1 and Figures 5 to 7; the maximum values of AC of ^{238}U, ^{232}Th and ^{40}K are 16.46±0.25 Bqkg^{-1}, 18.12±0.46 Bqkg^{-1} and 435.17±7.89 Bqkg^{-1} respectively which correspond to Benin, Ogwashi-Asaba and Ogwashi-Asaba geological formations. The values of AC of ^{40}K in soil are higher than the permissible value in formations such as Alluvium, Imo shales and Ameki; those obtained in Benin and Ogwashi-Asaba are within range. The concentrations of ^{238}U and ^{232}Th from the soil are also within range. All the activity concentrations noted from maize are above the maximum permissible limit. Ogwashi-asaba formation has deposits of limestone, clay, gravels, coal and ULiite compounds (AKSG, 2020).

Transfer factor

Equation 2 was adequate for the determination of TF. The mean values for ^{238}U, ^{232}Th and ^{40}K corresponds to 0.942, 0.460 and 1.002. Table 2 has the TF data and Figure 8 presents the percentage contribution of each radionuclide in Akwa Ibom State. Potassium has the highest value uptake of about 41%. Potassium is a major element needed for plant growth; plant absorb them from the soil thereby increasing its transfer factor. Thorium has the least uptake of about 20%. The percentage of Uranium is approximately 39% which is more mobile than Thorium and hence increases its concentration in the plant. However, the mean transfer factors obtained from the study was about unity. Figure 9 sorts each radionuclide according to their abundance or richness in the different geological formations. The highest TF (1.13) was from ^{40}K obtained at Benin formation which is above unity. Another TF of ^{40}K beyond unity was also noted at Ogwashi-Asaba formation. The high value of TR may be accredited to the richness of the organic matter in the soil.

Absorbed dose rate, radium equivalent and excess life cancer risk

These parameters were computed using Equations 4, 3 and 6 separately. Table 3, Figures 10, 12 and 13 present the facts. The absorbed dose rate in all geological formation ranges from 28.91 $nGyh^{-1}$ to 36.08 $nGyh^{-1}$. Alluvium has the highest value; Imo shale has the lowest. These are below the world permissible average of about 55 $nGyh^{-1}$. Radium equivalent varies from 49.40 $Bqkg^{-1}$ to 98.75 $Bqkg^{-1}$ with a mean value of 70.19 $Bqkg^{-1}$. Alluvium has the higher radium equivalent (Figure 12); Imo Shale has the lowest. Radium equivalent is also lower than the world permissible average of 370 $Bqkg^{-1}$. Almost equal value (0.15×10^{-3}) is noted for the mean excess lifetime cancer risk (Figure 13). Although value obtained from Imo Shale varies slightly (0.12×10^{-3}). This translate to the fact that 12 to 15 out of every 100000 persons are likely to come down with cancer fatality for a period of 70 years. These values are really below the world permissible limit of 0.29×10^{-3}.

Annual effective dose is the same throughout the formations and was determined with the use of Equation 5. Equations 8, 9 and 10 were suitable to solve for H_{ex}, H_{in} and I_γ respectively. The result is presented in Figure 12. Alluvium has the highest health risk value and Imo with the lowest. Both results show that there is no geological formation with health risk issue as the evidence realized is below unity being the world permissible average.

CONCLUSION

This work can be seen as the first research relating activity concentrations of maize to the geological formations in Akwa Ibom State. All activity concentrations determined from maize are above the maximum permissible limit including the concentrations of ^{40}K in soil samples taken from Alluvium, Imo shales and Ameki. However, Benin and Ogwashi-Asaba formations are within the limit. The mean transfer factor obtained is about unity. The high value of ^{40}K and transfer factor may be accredited to the richness of the organic matter in the soil. The absorbed dose rate, radium equivalent and excess life cancer risk findings indicate no threat. Therefore, none of the geological formation poses any health challenge when maize planted in these formations are eaten as the permissible limit is not exceeded.

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