ASSESSMENT OF ACTIVITY CONCENTRATION OF RADIONUCLIDES AND THEIR TRANSFER FACTORS FROM THE SOIL TO MAIZE PLANTS IN ESSIEN UDIM LOCAL GOVERNMENT AREA OF AKWA IBOM STATE, NIGERIA.

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ABSTRACT

Maize has been a major source of food consumed by people and animals but evaluation of radiological hazards due to consumption of the maize has not been carried out to ascertain any possible health hazards. At Essien Udim Local Government Area (LGA), the activity concentrations of radionuclides of ^{40}K, ^{238}U and ^{232}Th and their transfer factors from soil to maize seeds and stems have been conducted using a gamma ray spectroscopy coupled with NaI detector. A total of 21 samples comprising 7 soil specimens, 7 maize seeds and 7 maize stems were collected and analysed. The mean activity concentrations of the radionuclides in the soil, maize seeds and maize stems samples are respectively 433.24 ± 5.65 Bq/kg, 367.61 ± 6.19 Bq/kg, 603.11 ± 8.04 Bq/kg for ^{40}K, 12.66 ± 0.07 Bq/kg, 10.06 ± 0.06 Bq/kg, 39.94 ± 0.07 Bq/kg for ^{238}U and 3.07 ± 0.07 Bq/kg, 1.85 ± 0.06 Bq/kg, 3.03 ± 0.09 Bq/kg for ^{232}Th. Most of these obtained values are within the safety limits except for some values of ^{40}K and ^{238}U in maize stems which exceeded their safety limits. The mean of transfer factors of the radionuclides for the maize seeds and stems were 0.9858 and 1.5411 for ^{40}K, 1.0841 and 3.4970 for ^{238}U, 0.6768 and 1.1811 for ^{232}Th radionuclides. The transfer factors are higher in maize stems than seeds and in some cases, exceeded unity which is the safety recommended limit. The mean annual ingestion dose due to the consumption of the maize seeds is 0.3824 mSv/yr for adults and 0.2375 mSv/yr for children. These results show that maize consumption does not pose a radiological health hazard to the consumers of maize from the study area.

KEYWORDS: Radionuclei exposure, Transfer factor, soil to maize, human health hazard

INTRODUCTION

Living organisms on earth are continuously exposed to ionizing radiation from natural sources. Natural exposures arise mainly from the primordial radionuclides which are distributed widely and are present in almost all geological materials in the earth's environment. The most prominent means of exposing the public to radiation is through soil. They are known to contain long half-life radionuclides such as uranium-238, thorium-232 and potassium-40 and the knowledge of these radionuclides' distribution in an environment is necessary for the estimation of the effects of radiation exposure due to both terrestrial and extra-terrestrial sources (Thabayneh and Jazzar, 2012). These radionuclides which are known as Naturally Occurring Radioactive Materials, NORMs are the most prominent sources of exposing the public (plants and animals) to radiation (Santawamaitre *et al*., 2010). The knowledge of the level of radionuclides concentration in an environment is necessary for assessing the effect of radiation exposure to plants and human beings due to both terrestrial and extraterrestrial sources (Achola, 2009).

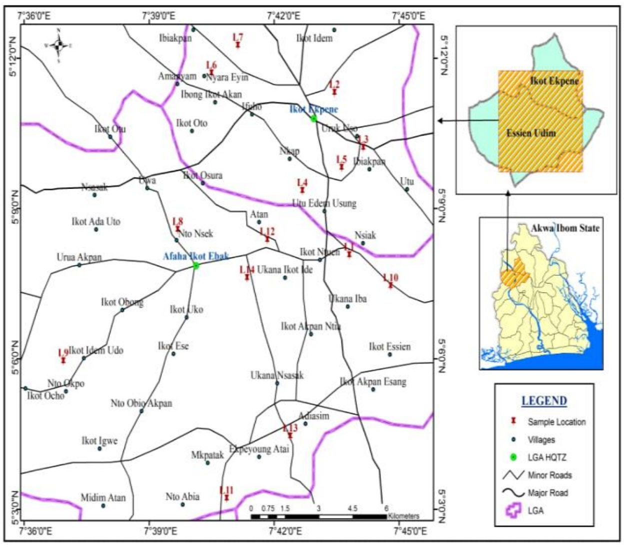
Terrestrial radiation is due to radioactive nuclides present in different amounts in rocks, building materials, water, soil and atmosphere (Essien and Emmanuel, 2016). These radionuclides are not evenly distributed within the soil ecosystem rather, they decay to release toxic ionizing radiations that can cause cancer and other detrimental health effects. The widespread of the radionuclides in the soil varies in geology, geographical and physiological conditions of the soil which constitute its migration from soil to plants in the terrestrial environment with a possible effect on the food chain (Akinyose *et al*., 2018). Radionuclides can be transferred into human body through various sources and pathways. Apart from atmospheric release, direct inhalation is the initial source of hazard to human (IAEA, 2011). Other sources of exposure of main concern are the radionuclides deposited on soils and on the foliage of crop plants, their uptake by the plant and water contaminations. The root uptake of radionuclides and the subsequent translocation to the edible plant parts are being influenced by many factors, such as soil characteristics, plant types, physiological processes in each compartment, competing ions, climatic conditions, physico-chemical form of the radionuclides and agricultural practices. The modelling of the radionuclide uptake by the root is a compromise between the availability of input parameters and scientifically based mechanistic approaches (Isikaye *et al*., 2013). Thus, there is a driving force to research and identify the amount of radionuclide being transfer from soil to different parts of maize plants (stem and maize seed) and its radiological hazard on humans. The majority of naturally occurring radionuclides belong to the radionuclides in the ^{238}U and ^{232}Th series and the single decay radionuclide ^{40}K (Akaninyene, *et al*, 2021). The terrestrial radioisotopes, thorium, uranium and potassium enter the human body through the food we eat that is by ingestion. Plants take up these radionuclides through their roots and accumulate in edible parts of the plants. When these plants are processed and consumed, the accumulated radionuclides constitute a hazard to humans. Much of our food directly or indirectly originates from plant materials, thus, detailed studies on plant contamination processes are an essential part of international environmental research. Transfer factor (TF) is an important parameter used in evaluation studies on the impact of routine and accidental release of radionuclides into the environment and the level of contamination of agricultural crops.). This ratio TF describes the amount of element expected to enter a plant from substrate under equilibrium conditions (Papastefanou *et al*., 2006).

MATERIALS AND METHOD

Location of the Study Area

The area is located between latitude 07º 36.95¹E and 07º44.78¹ and longitude 05º, 03¹ N and 05º, 12.23¹ N. It is bounded in the North by Abak, west by Ikot Ekpene local Government Areas of Akwa Ibom State. The population of the area is estimated to be about 560000 people according to the 2006 National Population Commission (NPC 2006) statistics. The map of the study is shown in Figure 1. The climate of the study area is an equatorial climate consisting of two major seasons; the rainy season (which usually starts in March and ends in October) and the dry season (which is from November to February) each year. There is no sharp boundary between these two seasons. The monthly mean surface temperature varies from 5.5ºC – 6.5⁰C from the annual mean temperature 29.2ºC. The maximum daily mean surface temperature is between 28ºC and 30ºC during March and the minimum daily mean temperature is between 23ºC and 24ºC in July and August. The rainfall in the study area is heavy with a mean monthly rainfall of about 135 mm during the rainy season 65mm during the dry season and an annual rainfall of between 2000 mm and 2250 mm.

Figure 1: The location map of the study area



Samples Collection

A total of twenty-one samples comprise of seven soil samples, seven maize seed samples and seven maize stem samples were randomly collected from seven selected farmlands in Essien Udim. For each sample collected, the soil positions were determined using the Global positioning system (GPS) detector. The soil surfaces were cleared of stones, pebbles, vegetation and roots according to avoid contamination with debris (Faanu, *et al.*, 2011). Soil samples of about 2.0 kg were collected from each soil position using a shovel and at a depth of 25-30 cm and were immediately stored in black polythene bags to ensure that radon gas did not escape from the samples (Chad-Umoren *et.al*, 2012). Maize stems and seeds were also collected from where the soil samples were collected and labeled appropriately.

Preparation of Samples.

The collected samples (soil, maize stems and maize seeds) were dried and then crushed, grounded and passed through a sieve of 1.0mm mesh size to separate coarse particles from the needed fine-grained powder. The coarse grains were discarded and fine-grained powder of each sample were dried in an oven, to about 110⁰c to ensure total removal of moisture (EL-Arah, 2005). To ascertain that water moisture was completely removed from the samples, a piece of water absorbing substance (thin sheet of paper) was inserted into the samples and there was no absorption of water from the samples by the paper. Each prepared sample were weighed 300 g and sealed in cylindrical plastic containers and labeled properly for easy identification. The prepared samples were stored for 30 days to ensure that they attained radioactive secular equilibrium between ^{236}Ra and ^{232}Th with their daughters (Essiett and Bede, 2016)

Sample Analysis

The gamma-ray spectrometry set-up used in the analyses consists of a highly shielded and well calibrated 3″ × 3″ NaI (Tl) (ORTEC) detector enclosed in a 2 mm thick copper, 2 mm thick cadmium and 10 cm thick lead shield, respectively, to assist in reducing background radiation. The energy resolution of the Nal (Tl) detector was determined to be 6.3% at 661.7 keV. In addition, the detector was coupled with a computer-based Multichannel Analyzer (MCA) with the MAESTRO (ORTEC) program, which was used for data acquisition and analysis of the gamma spectra. The samples were sent to the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria, for the determination of activity concentration of ^{238}U, ^{40}K, and ^{232}Th for each sample using sodium iodide (NaI) detector. The gamma spectroscopy analysis results were used to determine the radiological hazard parameters as well as the transfer factors for the study area. The activity concentrations of the radionuclides in the samples were obtained using Equation 1.

$$A = \frac{CPS \times 100}{E \times I \times W(gm)} \qquad 1$$

Where CPS is net count per second, E is counter efficiency, I intensity of gamma ray and W is weight of the sample.

Transfer Factors

The transfer factor of radionuclides is essential for estimating and predicting the radionuclide concentration in crops to calculate the radiological dose impact to human beings when the plants are ingested (Abiama *et. al.*, 2012). The soil-to-plant transfer factor (TF) is obtained for the radionuclides transfer from soil to plant. From the determined activity concentrations of the radionuclides in the plant and in the corresponding soil, the transfer factor values can be calculated using Equation 1b

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$$TF = \frac{Ap}{As} \quad 1b$$

Where Ap is the activity concentration of the radionuclides in plant (Bq/kg dry weight) and as is the activity concentration of the radionuclides in soil (Bq/kg dry weight) The soil-to-plant transfer factors obtained for the site shall be compared with the values reported by international recommended safety limits. (Vandenhove, *et.al,* 2009). Soil-plant transfer factor (TF) is one of the vital variables employed in assessing plants' uptake of radionuclides and their transfer to the food chain for predictive ingestion dose and risk evaluation (Otwoma *et al.*, 2013).

Effective Ingestion Dose of the Radionuclides

The effective ingestion dose due to the consumption of the radionuclides contaminated maize seeds and stems is a measure of the dose of radiation transported the human through the consumption of food stuffs. It is obtained by measuring the radionuclides activities concentration in the material and multiplying the activities by dose conversion factors and the mean annual consumption of the foodstuffs. The dose conversion coefficients for the respective radionuclides are given as 2.8 x 10^{-4}, 6.9 x 10^{-4} and 6.2 x 10^{-6} mSv/Bq for ^{238}U, ^{232}Th and ^{40}K respectively (Gauam, *et al.*, 2015). The determination of ingestion dose can be done using Equation 2.

$$E = C\sum A_i \, DCF_i \quad 2$$

Where C (kg/yr) is the mean annual consumption rate of the contaminated food stuff, A_i, (Bq/kg) is the activity concentration of the radionuclides in the ingested material and DCF_i is the dose coefficient for radionuclides while the summation is for all the radionuclides considered in the sample material under study. The annual consumption rate of maize in Akwa Ibom State is estimated at 45 kg/yr for children and 60 kg/yr for adults (NLSS, 2019).

RESULTS AND DISCUSSIONS

The activity concentrations of the radionuclides of ^{40}K, ^{238}U and ^{232}Th in the soil from Essien Udim are presented in Table 1.1. The values vary from (160.65 ± 4.22) Bq/kg at Nto Nsek to (766.30 ± 0.88) Bq/kg at Adiasim with an average of (443.24 ± 5.65) Bq/kg for ^{40}K, from (4.76 ± 0.08) Bq/kg at Nto Nsek to (24.60 ± 0.06) Bq/kg at Okon Ikot Edem with an average of (12.66 ± 0.07) Bq/kg for ^{238}U and from (1.94 ± 0.06) Bq/kg at Ukana Ikot Ide to (4.27 ± 0.09) Bq/kg at Ukana Onuk for ^{232}Th. The trend of dominant concentration of ^{40}K in the soil of the study area is similar to the trend in the values obtained Essien and Emmanuel, 2016, Essiett, *et. al.*, 2022. The average values of the activity concentration of ^{40}K, ^{238}U and ^{232}Th in the soil are lower than their world permissible maximum values of 450 Bq/kg, 35 Bq/kg and 30Bq/kg respectively, although some individual values exceed the safety limit for ^{40}K. Again, the activity concentrations of the radionuclides in the maize seeds show that the values vary from (213.46 ± 4.87) Bq/kg at Okon Ikotedem Udo to (871.15 ± 9.83) Bq/kg with a mean of (367.61 ± 6.19) Bq/kg for ^{40}K, from (7.08 ± 0.05) Bq/kg at Mkpatak to (18.55 ± 0.06) Bq/kg at Ukana Ikot Ide with a mean of (10.06 ± 0.06) Bq/kg for ^{238}U as well as from (1.35± 0.05) Bq/kg at Mkpatak to (2.31 ± 0.07) Bq/kg at Okon Ikotedem Udo with a mean of (1.85 ± 0.06) Bq/kg for ^{232}Th. Also, the activity concentrations of the radionuclides in the maize stems show that the values vary from (270.93 ± 5.48) Bq/kg at Nto Nsek to (819.22 ± 9.53) Bq/kg at Okon Ikotedem Udoe with a mean of (603.11 ± 8.04) Bq/kg for ^{40}K, from (4.24 ± 0.06) Bq/kg at Ukana Onuk to (207.94 ± 0.09) Bq/kg at Ukana Ikot Ide with a mean of (39.94 ± 0.07) Bq/kg for ^{238}U as well as from (1.31± 0.05) Bq/kg at Nto Nsek to (5.83 ± 0.11) Bq/kg at Adiasim Ikot Udo with a mean of (3.03 ± 0.09) Bq/kg for ^{232}Th. It was observed that the activity concentrations are greater in the stems than in the seeds and soil. Some of the values in the stems are above the world permissible limit (PML). This may be due to the transport system of the plant in which the stem is the major part and hence retains much of the radionuclides than the seeds. This dominant concentration of ^{40}K is in view of an important role play by potassium in the growth of plants. For plants, potassium is the second most importance constituent after nitrogen. A reduced potassium availability will cause growth to slow and the plant will extract the potassium from the leaves. As a positively charged ion, potassium is very important for the uptake and transport of negatively charged ions such as nitrate, phosphate and amino acids. Potassium plays a vital role in the translocation of sugars and starch from the leaves through the storage organs like fruits, bulbs and tubers.

Transfer Factors

Again, as contained in Table 1.2, the transfer factors in maize seeds has a mean value of 0.9858 for ^{40}K, 1.0841 for ^{238}U and 0.6768 for ^{232}Th. Also, the transfer factors for the maize stems has a mean of 1.5411 for ^{40}K, 3.4970 for ^{238}U and 1.1811 for ^{232}Th radionuclides. The comparisons of transfer factors of the radionuclides in maize stems and maize seeds with the world recommended safety limit in the study area is given in Figures 2 and 3 respectively. Some of the values are greater than the world permissible limit (PML) of 1.0 mostly in maize stems than maize seeds. These higher values of transfer factors in maize stems than maize seeds could be due to the fact that the stems have direct contact with the soil through the roots and concentrations of the radionuclides decrease in value as they are transported upwards along the stems to the seeds. The greater values of transfer factors may be due to the application of inorganic fertilizer to the soil that contained large percentage of the radionuclides.

Ingestion Dose due to the Consumption of the Maize seeds

The ingestion dose due the consumption of the contaminated radionuclides maize seeds is given in Table 3. In determining the values of the ingestion dose rate, the annual consumption rate of maize in Akwa Ibom State which is estimated at 45 kg/yr for children and 60 kg/yr for adults were used (NLSS, 2019). The mean values of the ingestion for adults and children were 0.3824 mSv/yr and 0.2375 mSv/yr respectively. These values are within the safety limit of unity. Hence, the consumption of maize seeds does not pose a significant health hazard the consumers

Table 1.1: Activity Concentration of the Radionuclides in soil, maize seeds and maize stems from Essien Udim

	Village	Code	^{40}K(Bq/kg)	^{238}U(Bq/kg)	^{232}Th(Bq/kg)
	Nto Nsek	AA1	160.65±4.22	4.76±0.08	3.56±0.08
	Okon Ikotedem udo	AB1	495.82±7.42	24.6±0.06	2.09±0.06
Soil	Ikpe Ikot Esire	AC1	470.08±7.22	7.37±0.08	3.24±0.08
	Mkpatak	AD1	459.65±7.14	7.83±0.08	3.21±0.08
	Ukana Onuk	AE1	233.1±5.09	9.88±0.09	4.27±0.09
	Adiasim Ikot Udo	AF1	766.3±0.88	22.09±0.07	2.69±0.07
	Ukana Ikot Ide	AG1	517.23±7.58	12.06±0.06	1.94±0.06
	Total		3102.68±39.55	88.59±0.52	21.52±0.52
	Mean		443.24±5.65	12.66±0.07	3.07±0.07
	Nto Nsek	AA2	321.96±5.98	9.81±0.05	1.56±0.05
	Okon Ikotedem udo	AB2	213.46±4.87	7.07±0.07	2.31±0.07
Maize Seeds	Ikpe Ikot Esire	AC2	365.46±6.37	11.83±0.07	1.56±0.05
	Mkpatak	AD2	335.71±6.1	7.08±0.05	1.35±0.05
	Ukana Onuk	AE2	223.11±4.98	8.28±0.06	2.16±0.06
	Adiasim Ikot Udo	AF2	242.64±5.19	7.83±0.07	1.92±0.06
	Ukana Ikot Ide	AG2	871.15±9.83	18.55±0.06	2.08±0.06
	Total		2573.49±9.83	70.45±0.43	12.94±0.4
	Mean		367.61±6.19	10.06±0.06	1.85±0.06
	Nto Nsek	AA3	270.93±5.48	9.88±0.05	1.31±0.05
	Okon Ikotedem udo	AB3	819.22±9.53	18.48±0.09	4.04±0.09
	Ikpe Ikot Esire	AC3	518.01±7.58	17.14±0.06	2.03±0.06
Maize Stems	Mkpatak	AD3	345.04±6.19	8.06±0.06	1.97±0.06
	Ukana Onuk	AE3	721.48±8.95	4.24±0.06	1.97±0.06
	Adiasim Ikot Udo	AF3	779.5±9.3	13.83±0.11	5.83±0.11
	Ukana Ikot Ide	AG3	767.57±9.23	207.94±0.09	4.07±0.09
	Total		4221.75±56.26	279.57±0.52	21.22±0.61
	Mean		603.11±8.04	39.94±0.07	3.03±0.09

Table 2: Transfer Factors of the radionuclides from soil to maize seeds and maize stems in Essien Udim

	Village	40- K	238-U	232-Th
	Nto Nsek	2.0041	2.0609	0.4382
	Okon Ikotedem udo	0.4305	0.2874	1.1053
	Ikpe Ikot Esire	0.7774	1.6052	0.4815
Maize Seeds	Mkpatak	0.7304	0.9042	0.4206
	Ukana Onuk	0.9571	0.8381	0.5056
	Adiasim Ikot Udo	0.3166	0.3545	0.7138
	Ukana Ikot Ide	1.6843	1.5381	1.0721
	Mean	0.9858	1.0841	0.6768
	Nto Nsek	1.6865	2.0756	0.3679
	Okon Ikotedem udo	1.6523	0.7512	1.9330
	Ikpe Ikot Esire	1.1019	2.3256	0.6265
	Mkpatak	0.7507	1.0294	0.6137
Maize Stems	Ukana Onuk	3.0952	0.4291	0.4614

Adiasim Ikot Udo	1.0172	0.6261	2.1673
Ukana Ikot Ide	1.4840	1.7242	2.0979
Mean	1.5411	3.4970	1.1811

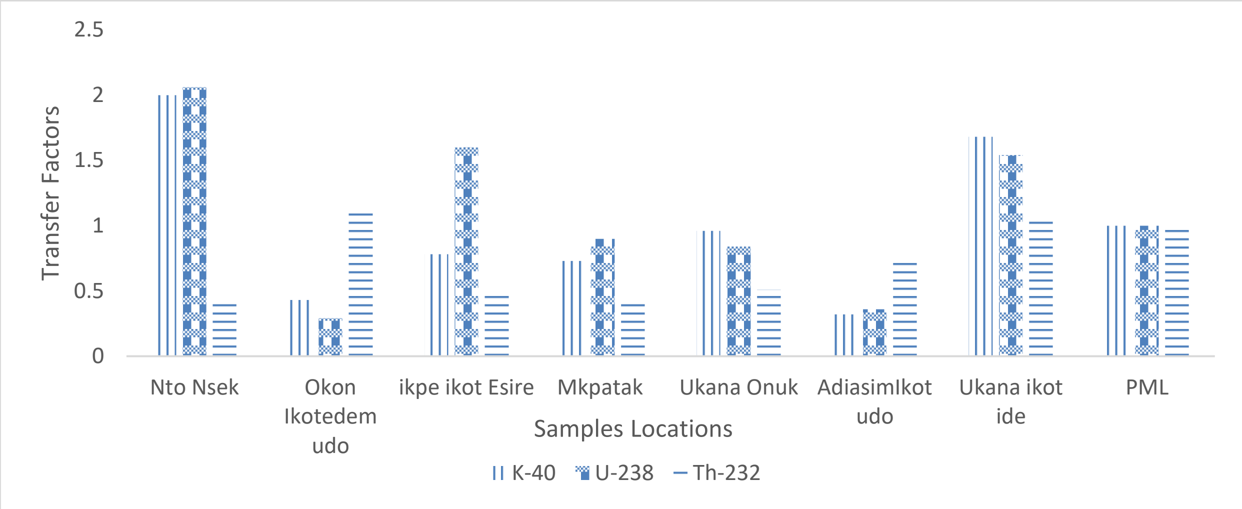

Figure 2: Comparison of transfer factors of ^{40}K, ^{238}U, ^{232}Th in maize seeds with PML .

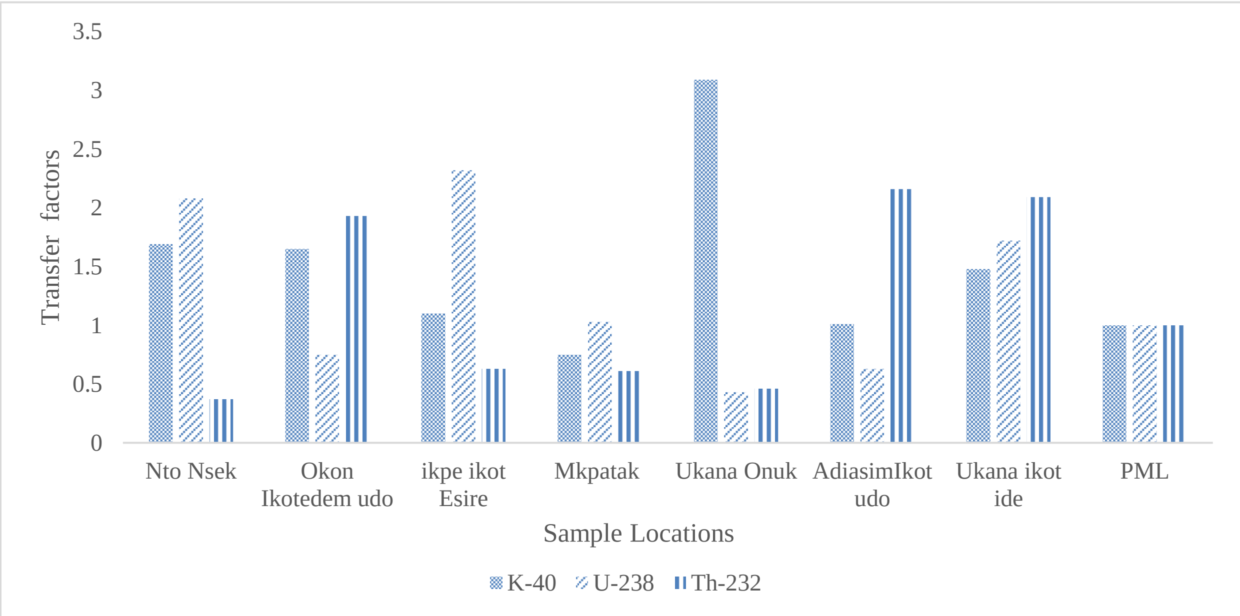

Figure 3: Comparison of transfer factors of ^{40}K, ^{238}U, ^{232}Th in maize stems with PML.

Table 3: Ingestion Dose due to the consumption of Maize Seeds at Essien Udim.

Village	Adult(mSv/yr)	Children(mSv/yr)
Nto Nsek	0.3491	0.2618
Okon Ikotedem udo	0.2938	0.2203
Ikpe Ikot Esire	0.3992	0.2994
Mkpatak	0.2997	0.1311
Ukana Onuk	0.3115	0.2084
adiasim ikot udo	0.3012	0.2259
Ukana Ikot Ide	0.7218	0.5414

Total	2.6766	1.6626
Mean	0.3824	0.2375

CONCLUSION

The assessment of radioactivity concentrations and transfer factors of the radionuclides to maize plant in Essien Udim Local government Area of Akwa Ibom state has been conducted. Some of the values of the radionuclides mostly in the maize stems exceeded their corresponding values in the soil, the maize seeds and the safety limits. Since the transfer factors in the maize stems exceeded the safety limit, the used of the maize stems for the feeding of livestock should be minimized to avoid transfer of excess radionuclides to man when the livestock is consumed.

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