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TRANSFER FACTORS OF ^{40}K, ^{232}TH AND ^{238}U FROM SOIL TO CASSAVA SYSTEM FROM FARMLANDS IN SELECTED PARTS OF AKWA IBOM STATE, NIGERIA.

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ABSTRACT
Naturally occurring radionuclide materials are known to exist in soils and can be transferred into plants and edible tubers like cassava which eventually gets into the food chain. This work was aimed at estimation of transfer factors of ^{40}K, ^{232}Th and ^{238}U in the soil to cassava-selected farmlands in Abak, Ikot Ekpene, Ukanafun and Etim Ekpo Local Government areas (LGA). The activity concentrations of twenty (20) soil samples and 15 Cassava samples from the farmlands were determined using gamma spectrometry. Measured mean activity concentrations of ^{40}K, ^{232}Th and ^{238}U in Abak soil samples were 475.74 ± 8.38 Bq/Kg), 57.21 ±0.98 Bq/Kg and 18.29 ± 0.35 (Bq/Kg). Ikot Ekpene soils were 539. 94 ± 8.35 (Bq/Kg), 62.28 ± 1.02 (Bq/Kg) and 17.84 ± 0.30 (Bq/Kg) respectively. Measured mean activity concentration for ^{40}K, ^{232}Th, and ^{238}U in Ukanafun soils were 485.46 ± 8. 62 Bq/Kg), 47.15 ±0.89 Bq/Kg, and 16.78 ± 0.28 (Bq/Kg). Etim Ekpo soils had mean activity concentrations of 431. 95 ± 8.20 (Bq/Kg), 51.00 ± 0.94 (Bqkg-1) and 16.67 ± 0.29 (Bq/Kg) respectively. Measured mean activity concentration for ^{40}K, ^{232}Th, and ^{238}U in Abak cassava were 593.94 ± 9.36 Bq/Kg), 19.29 ± 0.56 Bq/Kg and 17.09 ± 0.30 (Bq/Kg). Ikot Ekpene cassava shows mean activity concentrations of ^{40}K, ^{232}Th, and ^{238}U measured were 637.72 ±9.72 (Bq/Kg), 17. 79 ± 0.54 (Bq/Kg) and 18.19 ± 0.31 (Bq/Kg) respectively. Measured mean activity concentration for ^{40}K, ^{232}Th and ^{238}U in Ukanafun cassava samples were 614.55 ± 9.41 Bq/Kg), 22.27 ±0.62 Bq/Kg, and 15.19 ± 0.28 (Bq/Kg). Cassava in Etim Ekpo had mean activity concentrations of ^{40}K, ^{232}Th and ^{238}U of 581. 21 ± 10.06 (Bq/Kg), 21.08 ± 0.24 (Bq/Kg) and 16.36 ± 0.58 (Bq/Kg) respectively. The estimated transfer factors for ^{40}K were 1.28, 1.20, 1.39, and 1.35 respectively for Abak, Ikot Ekpene, Ukanafun, and Etim Ekpo. The mean transfer factor values for ^{232}Th were 0.36, 0.30, 0.49 and 0.43 while the mean transfer factor for ^{238}U was 0.93, 1.04, 0.91 and 1.08. The TF values for ^{40}K obtained for this work were higher than the recommended safe value of unity, while TF values for ^{232}Th and ^{238}U obtained for this work were very low. The variation in TF may be as a result of the geological properties of the area and the difference in the mobility rate of different radionuclides. However negligible the contamination is, the potential health risk could be minimised when food is cooked before being consumed.

KEYWORDS: Activity concentration; Soil; Cassava (*Manihot esculenta*); Radionuclides; Transfer factors;

INTRODUCTION
Radionuclides are matters that are obtained after the disintegration of radioactive materials, it ionizes the medium which interacts with it and affects the composition and nature of the medium. Naturally occurring radioactive materials (NORM) include ^{238}U, ^{232}Th, and ^{40}K. and are naturally found in the soil, air, water, and plants (Ekpo *et al.*, 2020). Each radionuclide has a characteristic half-life, which is the time required for half of the radioactive substance to undergo spontaneous decay. The decay introduces radioactive materials into the environment, hence raising the radioactivity levels of the environment. Humans being interacting with the contaminated environment may inhaled these radiations or ingest in food materials. The soil-plant-human pathway is recognized as a major pathway for the transfer of radionuclides to humans and animals (Ademola *et al.,* 2019). The transfer of these naturally occurring materials (NORMs) to plants is possible through the interaction of these NORMS with the root of the plant in the soil and the consequent uptake by plant and deposition of dust on plant leaves (Jibiri *et al.,* 2007). The rate of uptake of these NORMs by plants is determined by a model called the transfer factor (TF) which is defined as the ratio of the activity concentration of the radionuclides in the plant to the soil per unit mass. The consumptions of these radionuclide-contaminated food materials pose a potential health risk to its consumers (Essien *et al.,* 2016). Therefore, it is important to monitor the natural radionuclide levels in different food materials so as to determine the level of potential health risk of the food materials.

Cassava, scientifically known as *Manihot esculenta* is a tuberous edible plant cultivated throughout the Akwa Ibom State, Nigeria. Cassava is used in the production of cassava flour, breads, tapioca, a laundry starch, and an alcoholic beverage, animal feeds, and medicine It is one of the most valuable tuber crops grown and consumed extensively in almost every state in the Southern part of Nigeria by most households. It is among the major income-generating crops in many parts of Nigeria reported by Ejoh, *et al.* (2023).
This study was carried out to assess the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soils and cassava grown in Abak, Ikot Ekpene, Ukanafun and Etim Ekpo Local Government Areas of Akwa Ibom State and also to evaluate the transfer factors of these radionuclides into cassava.

MATERIALS AND METHOD
Description of Study Areas
The areas considered for the study were randomly selected from Abak, Ikot Ekpene, Ukanafun and Etim Ekpo L.G.A of

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Akwa Ibom State, Nigeria. A larger populace of these locations are largely farmers with interest in cassava planting because of the importance of cassava as a stable food for her indigenes. The locations of materials sampling in the different villages and their codes where samples were collected are also given in Table 1.

Table 1: Locations of sample collections

S/N	LGA	Location		Village	Codes
		Latitude	Longitude		
1	Abak	05°00.956'	007°47.916'	Oku Abak	AA
2				Oku Abak 2	AB
3				Abak 3	AO
4				Abak Itenge	AY
5	Ikot Ekpene	05°11.167'	007°43.400'	Ibiakpan farm	AK
6				Ikot Obio Edong	AP
7				Itak Ikot Ekpene	AT
8				Ikot Inyang	AW
9	Etim Ekpo	05°00.446'	007°37.739'	Ikot Eboro	AQ
10				Utu Annang	AX
11				Ikot Eboro 2	AZ
12	Ukanafun	04°57.782'	007°41.373'	Ukanafun 1	AS
13				Ukanafun 2	AV
14				Ukanafun 3	AU
15				Ukanafun 4	AD

Sample Collection, Preparation and Analysis

Method of sample collection was according to Essien *et al.*, (2021) where the top Soil of the sampling site was first scrapped to remove grasses, stones, or any contaminant, then the cassava is uprooted and soil samples are collected from the same spot using shovel. A total of fifteen soil and cassava samples were collected from the study areas. After collection, the cassava samples were washed with water to remove the soil on the surface. The samples were weighed and packed into polythene bags and carefully labelled per site to prevent samples mix up. The cassava tubers cut into pieces and the soil samples were sun dried for three days in order to remove moisture until constant weight was reached. The samples were crushed to powder form with mortar and then sieved with a 2 mm mesh sieve to obtain a homogenized sample. Thereafter, approximately 500 g each of the samples was transferred into some washed plastic containers of approximately uniform sizes, labelled and sent for analysis at the National Institute of Radiation Protection and Research (NIRPR) Ibadan, Oyo State Nigeria. Subsequently the samples were packed in Marinelli beakers to attain a good homogeneity around the NaI(Tl) detector. During each sample collection, Global Positioning System (GPS) was incorporated for the location of the coordinate of each sample station to be determined.

Radioactivity calculation

Specific activity concentration for each detected photo peak was calculated in using the relationship according to (Abojassim, *et al.*, 2016, Benjamin *et al.* 2022) given in Equation 1.

$$A\left(\frac{Bq}{kg}\right) = \frac{N - N0}{I\gamma\, \xi m t} \qquad (1)$$

Where A is the specific activity concentration of the radionuclide in the sample, N is the net counts of a given peak for a sample, N_0 is the background of the given peak, Iγ is the number of gamma photons per disintegration, ξ is the detector efficiency at the specific gamma- ray energy, m is the mass of the measured sample (weight in kg), and t is the measuring time for the sample.

Estimation of Soil-plant Transfer Factors

The soil-plant transfer factor (TF) is a model that measures the rate of transport radionuclides in the soil to plant and is the defined as the ratio of activity concentration in plant part (in Bq/ Kg dry weight) to the activity concentration of the soil (in Bq/Kg dry weight) using Equation 2 (Essien *et al.*, 2021, Ejoh *et al.*, 2023).

$$TF = \frac{A_P}{A_S} \qquad (2)$$

A_P is the $Activity\ concentration\ of\ radionuclides$ in plant (Bq /Kg), where A_S is the $Activity\ concentration\ of\ radionuclide\ in$ soil (Bq/Kg)

RESULTS AND DISCUSSION

Activity Concentration of Radionuclides in Soils

The mean measured activity concentrations (AC) of ^{40}K, ^{232}Th, and ^{238}U for the soils samples are presented in Table 1 while the range and mean activity concentrations are presented in (Fig.1). In Abak soils , AC of ^{40}K, ranged from 400.59 ± 7.70 Bq/Kg to 531.80 ± 7.87 Bq/Kg with a mean value of 475.74 ± 8.38 Bq/Kg, for ^{238}U mean AC ranged between 15.76 ± 0.28 Bq/Kg to 20.38 ± 0.32 Bq/Kg and a mean value 18.29 ± 0.35 Bq/Kg, activity concentration ^{232}Th ranged between 44.00 ± 0.86 Bq/Kg to 75.82 ± 1.13

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Bq/Kg with mean activity concentration of 57.21 ± 0.98 Bq/Kg.

In Ikot Ekpene soils, there are observed variations in the values of measured concentration activity of ^{40}K ranging between 464.20 ± 8.28 Bq/Kg to 590.97 ± 9.35 Bq/Kg with a mean value of 539.94 ± 8.39 Bq/Kg, ^{238}U has an AC range of 14.36 $\pm$0.24Bq/Kg to 18.12 ± 0.30 Bq/Kg with a mean value of 17.84 ± 0.30 Bq/Kg. Also, the AC ^{232}Th ranged between 51.32± 0.93 Bq/Kg to 74.03 $\pm$ 1.12 Bq/Kg with a mean value of 62.28 $\pm$ 1.02 Bq/Kg, Ukanafun soils measured AC varies as follows ^{40}K, of 434.46 ± 8.60 Bq/Kg to 555.32 ± 9.06 Bq/Kg with a mean value of 485.46$\pm$8.62 Bq/Kg, ^{238}U has an AC range of 14.36 $\pm$0.24 Bq/Kg to 20.33 ± 0.30 Bq/Kg with a mean value of 16.78 $\pm$ 0.28 Bq/Kg. Also, the AC of ^{232}Th ranged between 32.42± 0.74 Bq/Kg to 59.17 ± 1.00 Bq/Kg with a mean value of 47.15 ± 0.89 Bq/Kg.

The range and mean activity concentrations of ^{40}K, in Etim Ekpo soils (Table 2) were 468.49 ± 9.00 Bq/Kg to 400. 59 ± 7.70 Bq/Kg with a mean value of 431.95 ± 8.20 Bq/Kg, for ^{238}U the AC ranged between 23. 07 ± 0.34 Bq/Kg to 12.67 ± 0.25 Bq/Kg with a mean value of $16.67. \pm 0.29$ Bq/Kg, while ^{232}Th ranged AC of 58.26 ± 0.99 Bq/Kg to 52.93 ± 0.93 Bq/Kg with a mean value of 51. $\pm$0.94 Bq/Kg.

Table 2: Range /Mean value for activity concentration of radionuclide in soils (Bq/Kg) in the study areas

S/N	Sample location	Range/Mean	^{40}K (Bq/Kg)	^{232}Th (Bq/Kg)	^{238}U (Bq/Kg)
1-4	Abak	Range	531.80-400.59	75.82-44.00	20.38-15.76
		Mean	475.74±8.38	57.21±0.98	18.29±0.35
5-8	Ikot Ekpene	Range	590.97-464.20	74.03-51.32	19.99-14.53
		Mean	539.94± 8.39	62.28±1.02	17.84±0.30
9-12	Ukanafun	Range	555.32-434.46	59.17-32.42	20.23-14.36
		Mean	485.46±8.62	47.15±0.89	16.78±0.28
13-16	Etim Ekpo	Range	468.49-400.59	58.26-41.82	23.07-12.67
		Mean	431.95±8.20	51.00±0.94	8.01±0.29

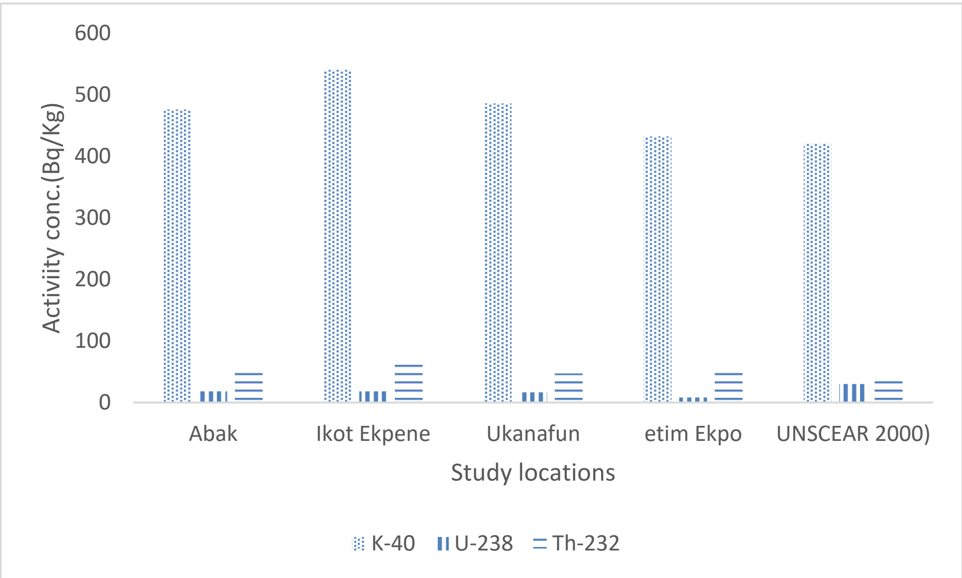

Figure 1: Mean activity concentration of radionuclides in soils per study areas.

It was observed in Figure 1, that the soils in Ikot Ekpene have the highest activity concentration of ^{40}K than in other locations. It was also observed that the activity concentrations of the radionuclides in the soil samples were higher than the global mean of 30 BqKg^{-1}for ^{238}U, 35 BqKg^{-1} for ^{232}Th and 420 BqKg^{-1}for ^{40}K (UNSCEAR, 2000) and higher than mean activity concentration of ^{40}K was 9.13 ±1.03 BqKg^{-1}, 5.91 ±0.66 BqKg^{-1} for ^{232}Th and 8.13 ±0.91 BqKg^{-1}for ^{238}U reported in farms soils from Ibiono Ibom (Essien and Akpan 2017). These values were lower than the values obtained in farm soils from the area under study and the recommended values (Benjamin *et al*. 2022).

Activity Concentration of Radionuclide in cassava

The results of the measured activity concentrations of the radionuclides in cassava as presented in Table 3 show that the AC of ^{40}K, ^{232}Th and ^{238}U distributions in cassava of the studied Local Government Areas as follows, in Abak, the AC of ^{40}K, ranged between 538.31 ± 8.92 Bq/Kg and 676.52 ± 10.0 Bq/Kg with a mean value of 593.94 ± 9.38 Bq/Kg, for ^{238}U mean activity concentration ranged between 13.07 $\pm$ 0.29 Bq/Kg and 20.35 $\pm$ 0.32 Bq/Kg and a mean value 17 .09 $\pm$ 0.30 Bq/Kg, activity concentration of ^{232}Th

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ranged between 9.35 ± 0.40 Bq/Kg to 26.26 ± 0.66 Bq/Kg with mean AC value of 19.29 ± 0.56 Bq/Kg.

Ikot Ekpene study shows variations in the values of measured AC of ^{40}K, as 592.45±9.36 Bq/Kg to 685. 94 ± 10.10 Bq/Kg with a mean value of 637.72 ± 9.72 Bq/Kg, ^{238}U has an AC range of 16. 14 ±0.29 Bq/Kg to 19.37 ± 0.32 Bq/Kg with a mean value of 18.19 ± 0.31 Bq/Kg. Also, the AC of ^{232}Th ranged between 12.80 ± 0.46 Bq/Kg to 22.23 ± 0.61 Bq/Kg with a mean value of 17.790.54 Bq/Kg.

The study of radionuclide in Ukanafun, presented variations in the values of measured AC of ^{40}K as 544.25 ± 8.50 Bq/Kg to 638.60 ± 10.09 Bq/Kg with a mean value of 614.55 ±9.41 Bq/Kg, ^{238}U has an AC range of 13.22 ±0.26 Bq/Kg to 18.06 ± 0.30 Bq/Kg with a mean value of 15.19 ± 0.28 Bq/Kg. Also, the AC ^{232}Th ranged between 15.91 ± 0.52 Bq/Kg to 24. 99 ± 0.66 Bq/Kg with a mean value of 22. 27 ± 0.62 Bq/Kg. The range of activity concentrations of ^{40}K, in Etim Ekpo cassava were 684.17 ± 10.06 Bq/Kg to 518. 34 ±8.75 Bq/Kg respectively with a mean value of 581.21 ± 10.06 Bq/Kg, for ^{238}U range of AC recorded were 18. 09 ± 0.30 Bq/Kg to 15. 57 ± 0.28 Bq/Kg with a mean value of 16.36 ±0.24 Bq/Kg, ^{232}Th recorded 26.50 ± 0.67 Bq/Kg, 16. 23 ± 0.52 Bq/Kg respectively with a mean value of 21. 08 ± 0.58Bq/Kg.

The radionuclides activity concentration values obtained in cassava samples are higher than the worldwide safe mean of 33 Bq/Kg for ^{238}U, 45 Bq/Kg for ^{232}Th and 420 Bq/Kg for ^{40}K (UNSCEAR 2000) and higher than the mean activity concentration of ^{40}K of 459.65±25.64 Bq/Kg, 6.80±0.45 Bq/Kg for ^{232}Th and 13.29±1.28 Bq/Kg for ^{238}U as was previously reported in other selected farms soils from Akwa Ibom State by Essiett *et al.*, (2022). The higher value of ^{40}K in the soils in the study areas could be attributed to the variation in the distribution of these radionuclides in their soils and the application of fertilizer as reported in other studies (Kahter and Sewaidan, 2008) Again, the higher concentration of ^{40}K in the tuber than ^{232}Th and ^{238}Uis from the fact that ^{40}K is an essential element required for plant growth (Adesiji, *et al.*, 2019, Alausa, 2016) hence there is a higher migration of the radionuclide from the soil to cassava than others, again it could be due to the smaller size of the atom/particles (Banzi *et al.*, 200.

Table 3: Range/Mean value of activity concentration of radionuclide in Cassava (Bq/kg) in the study area

S/N	Sample location	Range/Mean	^{40}K (Bq/Kg)	^{232}Th (Bq/Kg)	^{238}U (Bq/Kg)
1-4	Abak	Range	676.52-538.31	26.26-9.35	20.35-13.07
		Mean	593.94±9.36	19.29±0.56	17.09±0.30
5-8	Ikot Ekpene	Range	685.94-592.45	22.23-12.80	19.37-16.14
		Mean	637.72±9.72	17.79±0.54	18.19±0.31
9-12	Ukanafun	Range	638.60-544.25	24.99-15.91	18.06-13.22
		Mean	614.55±9.41	22.27±0.62	15.19±0.28
13-16	Etim Ekpo	Range	684.17-518.34	26.50-16.23	18.09-15.57
		Mean	581.21±10.06	21.08±0.24	16.36±0.58

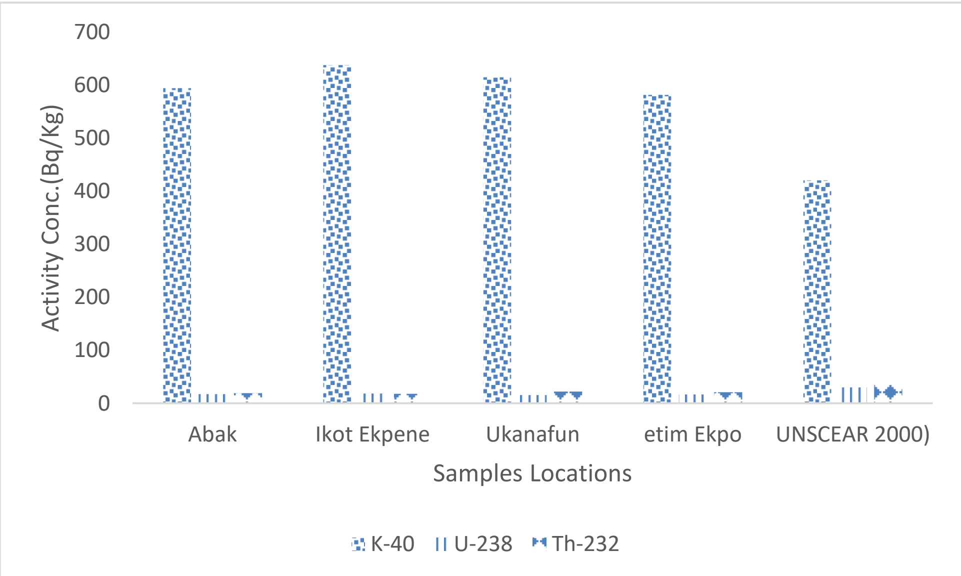

Fig. 2: Mean activity concentrations of radionuclides in cassava

Estimation of Transfer Factors

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Transfer Factor of Radionuclides from Soil to Cassava (TF) is defined as the ratio of radionuclide concentrations in cassava and soil which is a model used in estimating the radionuclide concentrations in agriculture crops for estimating dose intake by man. The estimated TF of ^{40}K, ^{232}Th and ^{238}U were determined and presented in Figure 3.

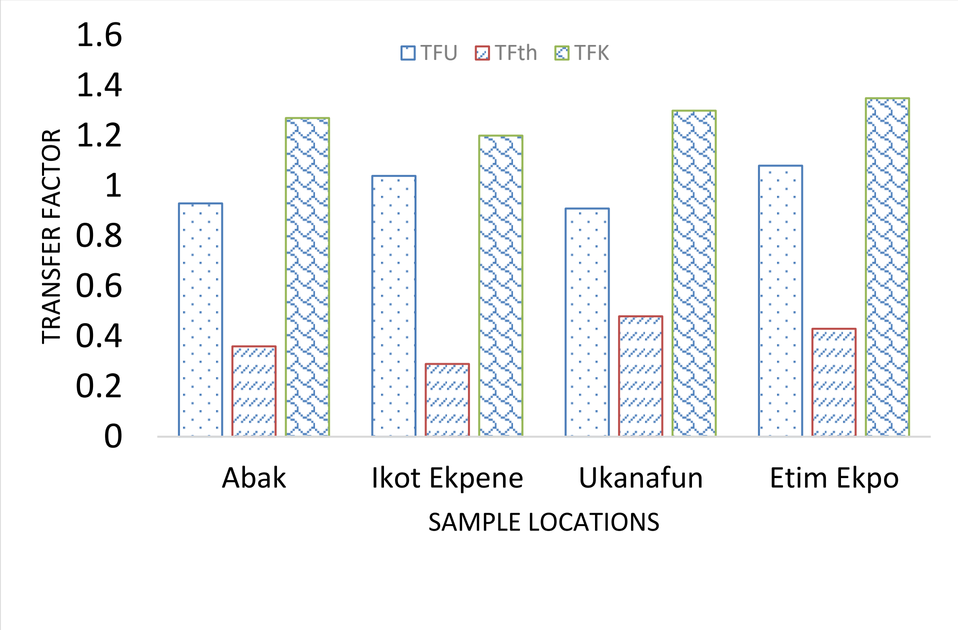

Figure 3: Transfer Factors of ^{238}U, ^{232}Th and ^{40}K

Transfer Factors

The mean TFs for ^{40}K were 1.28, 1.20, 1.39 and 1.35 respectively for Abak, Ikot Ekpene, Ukanafun and Etim Ekpo. The TF of ^{40} K for Etim Ekpo was higher than in other locations of the study area. The mean TFs for ^{232}Th were 0.36, 0.30, 0.49, and 0.43 respectively for each of the study locations. Ukanafun location has the highest. The mean TFs for ^{238}U were 0.93 ,1.04, 0.91 and 1.08. The TF of ^{238}U in Etim Ekpo cassava being the highest compared to other districts of the study area. The TF value for ^{40}K obtained for this work were higher than 1.0 showing that the rate of transfer of ^{40}K and its absorption by cassava was high and also the fact that potassium has less affinity to the soil and highly soluble. The high transfer factor also accounts for the reason why the mean activity concentration of ^{40}K in cassava is higher the value in soils of the studied areas. Transfer Factors values for ^{232}Th and ^{238}U obtained for this work were very low showing no significant uptake of ^{238}U and ^{232}Th by cassava. This is because they have strong affinity to the soil, less soluble and less mobile in the soil than potassium (Adesiji *et al.*, 2019, Alausa, 2016). The variation in TF result may be due to the differences in the geological properties of the area and radionuclide distribution. It is also observed that the TF of the radionuclides to cassava is higher while the mean activity concentration of radionuclides in soil is less, this agrees with findings obtained in other works (Essiett, *et al.*, 2022, Essien *et al*, 2021) showing that TF is not linearly related to radionuclides activity concentration in soil. Moreover, the rate of transfer of ^{232}Th is higher than ^{238}U in this study as also reported in other works (Martinez *et al.*, 1995).

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