Original Research Article

Radioactivity levels in maize from high background radiation areas and dose estimates for the public in Tanzania

Abstract

Natural radioactivity levels in maize which is one of the staple foods in various regions in Tanzania have been studied. The radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K were determined using γ ray spectrometry employing HPGe detector of relative efficiency of 51 %. The average radioactivity concentrations in maize from five regions were ranged from 1.8 ± 0.2 to 23.6 ± 0.7 Bq/kg ^{238}U, 2.2 ± 0.1 to 38.9 ± 1.0 Bq/kg for ^{232}Th and 42.0 ± 0.4 to 434.6 ± 18.7 Bq/kg for ^{40}K respectively. Total annual committed effective dose due to total ^{238}U and ^{232}Th intakes as a result of consumption of maize in five Regions were as follows; Manyara (1.46 mSv/y), Mbeya (0.31 mSv/y), Dodoma (0.21 mSv/y), Ruvuma (0.19 mSv/y) and Dar es Salaam (0.08 mSv/y). The dose value from Manyara was almost the same to the annual dose guideline for the general public which is 1 mSv/y, where as for other regions the doses are low. Hence a conclusion could be made that food crops cultivated at Minjingu village might expose the population to high radiation dose which might be detrimental to their health.

Keywords: Radioactivity, Minjingu phosphate deposit, committed effective dose, Uranium Deposit

1. Introduction

The knowledge of natural radioactivity in man and his environment is very important since naturally occurring radionuclides are the major sources of radiation exposure to man [1]. Radionuclides enter the human body through complex mechanism including ingested foodstuffs via the food chain from natural sources. Ingestion of radionuclides through food intake accounts for a substantial part of average radiation doses to various organs of the body and also represents one of the important pathways for long term health considerations. Radionuclide have always been present in food at various levels depending on factors such as radioactivity contents in soil and the transfer characteristics from the environment medium to food for other regions the dose values are lower stuff and hence to man [2]. The status of the soil on which food crops are grown determines, to a significant extent, the quality of food crops produced, the season of the year also determines to a great extent the magnitude of contamination of different foods [2].

In Tanzania, the main source of contamination of agricultural soils is through natural occurring radioactive materials (NORMs) and application of fertilizers. All minerals and raw material contains radionuclide of natural origin, sometimes the radioactivity of those radionuclides is higher than the normal background and might exceed the world limits. The most important for the purposes of radiation protection are the radionuclides in the ^{238}U and ^{232}Th decay series. In the recent years, extensive uranium exploration and feasibility studies in Tanzania have found several sites with economically viable uranium deposits. In 2009, deposits of uranium were discovered at Mkuju, Namtumbo district, southern Tanzania [3]. This discovery was followed by Manyoni uranium deposits (Singida region) and Bahi uranium deposits (Dodoma region) both in Central Tanzania [4]. Furthermore, Tanzania has several phosphate deposits (Figure 1); however, the biggest one is Minjingu phosphate deposit found in Manyara region [5]. These discoveries of uranium deposit at Mkuju in Ruvuma and Bahi in Dodoma region and the presence of phosphate deposit and mine at Minjingu village in Manyara region has brought concern about the levels of natural radioactivity in soil and in locally grown food crops at the areas in the neighbourhood of the deposits.

The soil samples from Likuyu village in Ruvuma region had an average radioactivity as follows. For ^{238}U the concentration was 51.7 ± 3.8 Bq/kg, ^{232}Th was 36.4 ± 3.1 Bq/kg and ^{40}K was 564.3 ± 9.9 Bq/kg [6]. At Bahi District in Dodoma, the level of radioactivity in soils was reported as for ^{226}Ra the concentration was 25.2 ± 5.4 Bq/kg, ^{232}Th was 37.2 ± 10.7 Bq/kg and ^{40}K was 494.9 ± 6.2 Bq/kg [7]. These values were higher than the average activity concentrations of Tanzania soils which are 350.4 ± 18.3, 24.7 ± 2.2 and 34.2 ± 2.0 Bq/kg for ^{40}K, ^{232}Th and ^{238}U [8]. However, these radioactivity values were higher than the world average activities of the same radionuclides. Worldwide there are reports which indicate high radioactivity levels in regions near uranium deposits. Reports from Madagascar and India showed that the level of ^{238}U and ^{232}Th and their daughters in the soil around the uranium deposit was high compared to the world average [9]. It has been reported high activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil around Gurvanbulag uranium deposit in the eastern part of Mongolia [10]. Soils around the phosphate deposit have been reported to contain relatively high concentration of ^{238}U and ^{232}Th and their daughters. The rock phosphate from Minjingu contains uranium concentration of (480 – 1100 ppm) contrast to other rocks in the world [8]. Also the rock phosphate had the activity of 286, 698 and 5022 Bq/kg for ^{40}K, ^{232}Th and ^{238}U respectively [5]. The fertilizer (Triple superphosphate) manufactured from Minjingu phosphate rock are also reported to have high activities of 362, 444 and 3116 for ^{40}K, ^{232}Th and ^{238}U, and for Superphosphate, the following activities 491, 433 and 3394 for ^{40}K, ^{232}Th and ^{238}U were reported [5]. Therefore, the extensive use of phosphate fertilizers for agriculture in Mbeya region might contribute significantly to activity levels of farm soils [11] and then to maize via root uptake.

Studies on radioactivity in food crops grown in high background radiation areas have been reported worldwide [12]. In Tanzania, radioactivity levels in edible leaf vegetation, maize and mung beans has been reported in Minjingu [8, 13]. Maize is the food crop that is highly consumed at highest rates and forms the most important part of the daily diet for wide range of population ages. For instance, soft plain maize porridge is the most common infant food consumed daily by 94 % of the infants in Tanzania [14]. Based on the understanding of agricultural practices that utilizes some phosphate fertilizers and food consumption patterns in mentioned areas in Tanzania, understanding the activity levels for maize crop is wealthy.

Therefore, the aim of this study is to determine the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in maize from selected regions in Tanzania and to estimate the internal exposure due to ^{232}Th and ^{238}U intakes to individuals (> 17 years) due to maize consuming. The effective dose will also be calculated and compared to the ICRP and UNSCEAR values.

2. Material and Methods

2.1 Selection of Sampling sites

The sampling sites were identified basing on their characteristics (Figure 1). In Manyara region, maize was sampled from Minjingu village where there is the biggest phosphate deposit and the only active phosphate mine in Tanzania [8]. In Ruvuma region, maize was sampled from Likuyu village, this village is situated about 54 km east of the Mkuju uranium deposit [6]. In Dodoma, maize sample were collected at Bahi Wetlands which is situated about 60 km north-west of the capital Dodoma.

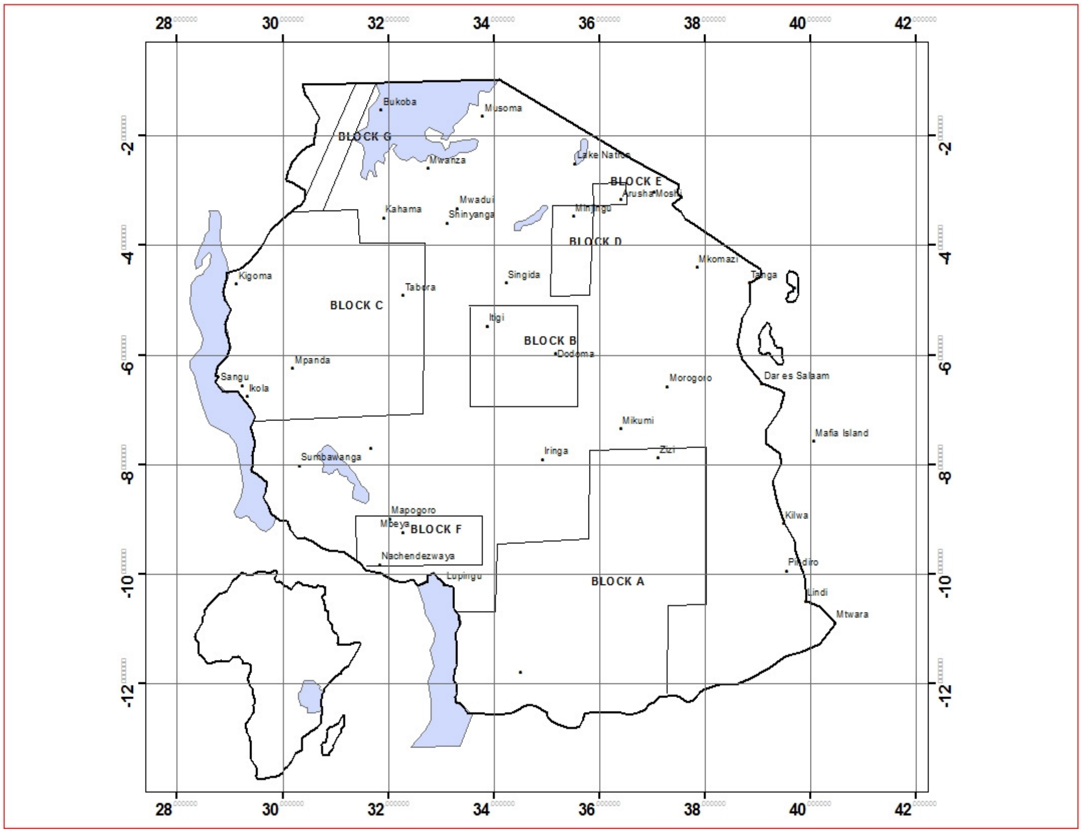

Figure.1. Map of Tanzania showing the discovered Phosphate deposits (the dots) and Uranium (Blocks A-G) occurrences in different geological environment. The inset shows its relative position in African Continent.

Table 1. Shows block name, Locations and Area coverage of discovered Uranium occurrences in different geological environment in Tanzania.

Block Name	*Deposits Locations*	*Occurrences Area (Sq. km)*
A	Mkuju, Madaba	135,000
B	Isuna, Bahi, Makutupora	37,000
C	Ndala, Igombe, Kigoma	142,000
	Ugalla River, Mpanda	
D	Minjingu, Gallapo	13,000
E	Monduli, Tarosero	2,000
F	Chimala, Panda, Njombe	19,000
G	Bukoba, Biharamulo	10,000

Through the survey it was revealed that maize available in the city markets of Tanzania were mostly supplied from Mbeya [11]. Therefore, a fourth batch of maize samples was from Mbeya (Mbozi and Usangu), as it was one of the major maize growing area in the country and also uses the phosphate fertilizers from Minjingu [11]. Moreover, Dar es Salaam region, the capital city imports maize originate from several areas in Tanzania, maize samples were collected from different market and mills at Tandika, Manzese and Gongolamboto in Dar es Salaam region, the business city in Tanzania.

2.2 Sample collection and preparation

Sampling was carried out between March and June, 2015 in all five regions. A total of 80 maize samples were collected. 20 samples from Minjingu (Manyara), 15 samples from Likuyu (Ruvuma), 15 samples from Bahi (Dodoma) and 15 samples from Mbozi and Usangu (Mbeya), and 15 samples from Dar es Salaam. Maize was collect from farms in Minjingu and Likuyu villages. However, in Mbeya and Dar es Salaam city, maize samples were collected from markets and milling areas. Maize samples were prepared as for cooking which include washing. Samples were sun dried for 2 days and then oven dried at 45 - 50 ^{o}C for 48 hours. They were then crushed into small grains using mortar and pestle, and by using MonoMill Pulverrizer, the samples were pulverized into powder, then sieved to reduce particle size to the recommended size of (< 50 µm) [2], and then dried in the desiccator for one week while several series of weight measurement were taken to note when constant weights in samples were achieved. Finally, 100g of each sample was packed into cylindrical stainless steel canister to a height of 1.8 cm, sealed using glycerin and wrapped by using gas tightness insulation tape to avoid escape of radon gas. Samples were stored for more than 21 days to allow attainment of radioactive equilibrium stage between ^{226}Ra and its short lived decay products

2.3 Instrumentation

A lead shielded vertical coaxial (n-type) HPGe detector of relative efficiency of 51 % and resolution of 1.8 keV at 1332 keV (from ^{60}Co source) was used for low level counting of samples. The HPGe detector was well housed reduce background in three layers of copper, cadmium and lead of 30 mm, 3mm and 100 mm respectively. The detector was connected to a Digital Spectrum Analyzer; DSA100 with built in Multichannel analyzer (MCA) and employed genie 2000 software for analysis. The energy and efficiency calibrations of the γ-spectrometry system were performed using five standard radioactive sources (^{155}Eu, ^{137}Cs, ^{60}Co, ^{22}Na and ^{40}K). The descriptions of the gamma spectrometry system as well as more details on the calibrations and the analytical methods used into this study are well documented elsewhere [2, 15].

An empty cylindrical steel canister with the same geometry as that of the sample was used as background activities of radionuclides as well as their minimum detection limits. The counting time for accumulating spectral for both the samples and background was set at 28,800s. However, in order to check the stability of the system, each container was counted twice. The detection limits of the detector for the concentration of radionuclides were determined as documented elsewhere [16]. The detection limits for 295.21 keV (1.23 Bq/kg), 351.92 keV (0.69 Bq/kg), 609.31 keV (0.95 Bq/kg), 1120.29 keV (3.17 Bq/kg), 338.32 keV (0.96 Bq/kg), 911.60 keV (3.61 Bq/kg), 969.11 keV (0.74 Bq/kg), 583.19 keV (1.96 Bq/kg), 860.50 keV (2.45 Bq/kg) and 1460.81 keV (18.10 Bq/kg). The radioactivity concentrations below these values have been taken to be below the minimum detection limit (BDL).

The specific radioactivity in maize samples were estimated by taking the mean of specific radioactivities obtained from the γ - ray lines from their daughters. ^{238}U activity concentration in maize samples were determined via its daughters through intensities of the ^{214}Pb (295.21 keV and 351.92 keV) and ^{214}Bi (609.31 keV and 1120.29 keV) γ lines, respectively. ^{232}Th activity concentration were obtained through ^{228}Ac (338.32 keV, 911.60 keV and 969.11 keV) and ^{208}Tl (583.19 keV and 860.50 keV) γ lines, while that of ^{40}K was determined directly by the γ - line of energy 1460.81 keV.

For quality assurance, the IAEA Soil 375 standard reference material (SRM) weighed (164 g) in the same method as the samples and packed in cylindrical stainless steel canister at a height of 1.8 cm. As Table 2 shows, the experimental values agreed well with the recommended values approximately within ± 7.5 % accuracy for ^{238}U, ±10.7 % for ^{232}Th and ±10 % for ^{40}K.

Table 2: The Standard Reference Values and Experimental Values of the IAEA Reference Soil 375 [17]

Radionuclide	Experimental Activity	Certified Value	% Deviation from Certified Value (±)
^{238}U	21.5	20.0	7.5
^{232}Th	22.7	20.5	10.7
^{40}K	466.4	424	10.0

2.4 Effective dose estimation

The committed effective dose due to the intake of radionuclides through maize was calculated using the equation below.

$$E = D_{ing} F C_i \quad 1$$

Where, E is the annual committed effective dose from consumption of nuclide i in maize (mSv/year), C_i is the concentration of radionuclide i in maize at the time of consumption (Bq/kg), F is the maize consumption rate among Tanzanians (kg/year), and D_{ing} is the dose coefficient for ingestion of radionuclide i (mSv/Bq) given by ICRP (1996), which varies with both radionuclides and the age of individuals. The total committed effective dose (E) to an individual from radionuclide i in maize was established by summing contributions from all nuclides (^{238}U and ^{232}Th) present in maize.

3. Results and Discussion

3.1 Radioactivity in maize

The activity concentrations due to ^{238}U, ^{232}Th and ^{40}K in the maize samples collected in all five regions in Tanzania are presented in Table 3. The results show that the activity levels of radionuclide is higher for samples collected from Minjingu areas, Manyara Regions where the phosphate mining and factory for phosphate fertilizers is located. Followed on the list are samples from Mbeya Regions which can be contributed by use phosphate fertilizers from Minjingu phosphate fertilizers factory. The activity levels of radionuclides in maize from Bahi in Dodoma region occupied a third place while that of Ruvuma in Likuyu village occupied a fourth palace. The values in Bahi and Likuyu village are low because the uranium deposit is not in operation, and hence this result can be used as baseline data.

The observed low activity levels for samples from Dar es Salaam markets may be due to the facts that the sample collected could be supplied from other regions where the use of fertilizers is low. The average activity levels of these radionuclides in maize were found to be compared to those of maize from Nigeria [12, 18], India, Bangladesh, Iran and Brazil [19, 20, and 21]. As expected, the activity concentration of ^{40}K was higher in all the maize samples than the activities of ^{238}U and ^{232}Th.

Table 3: Radioactivity concentration (Bq/kg) in Maize samples collected from five Regions in Tanzania

	Activity concentration (Bq/kg ± SEM)		
	^{238}U	^{232}Th	^{40}K
MANYARA (Minjingu village)	< 21.1 – 31.8 > [a] 23.6 ± 0.7 [b]	< 28.7 – 64.1 > 38.9 ± 1.0	< 260.7 – 548.4 > 434.6 ± 18.7
MBEYA (Usangu and Mbozi)	< 6.6 – 46.2 > 16.4 ± 0.2	< BDL – 23.7 > 6.0 ± 0.1	< 43.2 – 88.0 > 55.6 ± 0.2
DODOMA (Bahi Waterlands)	< 1.2 – 4.9 > 2.4 ± 0.3	< 7.9 – 19.8 > 5.6 ± 0.2	< 13.8– 38.7 > 26.5 ± 4.5
RUVUMA (Likuyu Village)	< 2.3 – 6.7 > 3.2 ± 0.2	< 8.6 – 15.2 > 5.0 ± 0.3	< 18.9 – 44.4 > 32.5 ± 7.2
DAR ES SALAAM (Markets and Mills)	< BDL – 22.4 > 1.8 ± 0.2	< BDL – 8.8 > 2.2 ± 0.1	< 32.1 – 50.8 > 42.0 ± 0.4

a: represents the range of radioactivity concentration
b: represents the average radioactivity concentration

3.2 Effective dose due to ingestion

Effective dose is a useful concept that enables the radiation doses from different radionuclides and from different types and sources of radioactivity to be added. The impact of internal dose risk of the population in Tanzania due to consumption of maize was estimated using the average maize consumption rate (kg/y) and dose coefficients (mSv/Bq), as reported in Table 4. The maize consumption rates in this study were found from the survey to be 151.2 kg capita^{-1} year^{-1} in Minjingu and 140.6 kg capita^{-1} year^{-1} in Mbozi, respectively. On averaging we have 145.9 kg capita^{-1} year^{-1}, this value was assumed to represent the maize consumption rate in areas of the study.

Total annual committed effective doses due to ^{232}Th and ^{238}U intakes as a result of consumption of maize in Tanzania are 1.46 mSv/y in Manyara, 0.31 mSv/y in Mbeya, 0.21 mSv/y in Dodoma, 0.19 mSv/y in Ruvuma and 0.08 mSv/y in Dar es Salam, respectively (Table 4). The main dose contribution is from ^{232}Th. The doses estimated in this paper could be refined if specific data on consumption rates were available. These values are below the annual dose guideline of 1mSv/y recommended by the ICRP for the general public except the dose value from Manyara (Minjingu village). However, the annual dose limit of 1 mSv/y is strictly applied to controlled releases.

^{40}K is an essential biological element distributed throughout the body and its concentration in human tissue is under metabolic (homeostatic) control. Thus the levels in humans are not normally affected by variations in the environmental levels and as a result its radiation dose within the body remain constant [22].

Table 4: Annual committed effective dose value due to ^{238}U and ^{232}Th intake in Maize

REGION (Area)	Effective dose (mSv/y ± SEM)		
	^{238}U	^{232}Th	Total dose
MANYARA (Minjingu village)	0.155 ± 0.005	1.305 ± 0.034	**1.460 ± 0.039**
MBEYA (Usangu and Mbozi)	0.108 ± 0.001	0.201 ± 0.003	**0.309 ± 0.004**
DODOMA (Bahi Waterlands)	0.016 ± 0.002	0.188 ± 0.007	**0.204 ± 0.009**
RUVUMA (Likuyu village)	0.021 ± 0.001	0.168 ± 0.010	**0.189 ± 0.011**
DAR ES SALAAM (Markets and Mills)	0.012 ± 0.001	0.074 ± 0.003	**0.086 ± 0.004**

4. Conclusion

The radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th in maize from high background radiation are in Tanzania has been estimated and discussed. The comparison was made with radioactivity of maize around the globe. The annual committed effective dose due to ingestion of maize in Tanzania was also estimated by using the radioactivity concentrations. The annual committed effective doses due to ^{232}Th and ^{238}U intakes are below annual dose guideline (1 mSv/y) for the general public from naturally occurring radionuclides [23], except the dose value from Minjingu in Manyara region. However, they are considered to be sufficiently low to result in negligible harmful effects. Further studies on other types of foods and drinking water, as well as the dose contributions from ^{223}Ra and its daughters are recommended.

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