__Original Research Article__

Natural Radioactivity in Vegetables from Selected Areas of Manyoni District in Central Tanzania

ABSTRACT

The study determined the mean concentrations of natural radionuclides, the annual intake of radionuclides and annual effective dose due to the ingestion of Vegetables from selected areas of Manyoni in Tanzania. A total of 30 leafy vegetable samples grouped into five categories were collected randomly from different locations of the study area. The activity concentration levels of U-238, Th-232, and K-40 were measured by direct γ-ray spectrometry using HPGe detector by Compton suppression method. The radioactivity in vegetables ranged from 2.2 Bq/kg – 36.8 Bq/kg for U-238, 4.1 Bq/kg – 30.1 Bq/kg for Th-232 and 700.0 Bq/kg – 2520.0 Bq/kg for K-40, respectively. Except for K-40, the activity levels reported into this study were lower than the activity levels of vegetables reported from various parts of Tanzania. However, the concentrations of radionuclides in the vegetables samples found in this study were higher than the world average values suggested by the UNSCEAR. The annual effective dose due to intake of vegetables was 2.73 mSv/year. This dose value was found 9.4 times higher than total exposure per person resulting from the ingestion of terrestrial radionuclides as proposed by UNSCEAR. Also the dose was higher than the annual dose limit of 1 mSv/year recommended by the ICRP for the general public. The annual intakes of U-238 and Th-232 in vegetables were much higher than the world reference value in diets. Hence a conclusion could be made that vegetables cultivated in Manyoni might expose the population to high radiation dose which might be detrimental to their health.

Key Worlds: Uranium deposit; Radioactivity; Effective dose; Annual intake of radionuclides

1. INTRODUCTION

The knowledge of radionuclides concentration and distribution in vegetation is of interest (in environmental radiological protection) not only for an accurate determination of activity but to assess the effects and potential hazard of radiation exposure inherent in the measured activity to human and biota [1]. More interests have been arisen to minimize the hazards caused by ionizing radiation from manmade or naturally occurring radioactive materials [1]. In the past people paid the price for little or improper knowledge on the effect of ionizing radiation. However the emphasis on radiation protection, safety and security of radioactive sources has positively contributed to reduce such hazards as the people's awareness has apparently been enhanced [2].

Natural radionuclides occur in soil and they are incorporated metabolically into plants, and ultimately find their way into food crops and water [3]. Man-made radionuclides behave in a similar manner, and worldwide contamination of the food chains by radionuclides produced during nuclear weapons tests in the atmosphere has taken place during the past half century [4]. 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 [5]. This discovery was followed by Manyoni uranium deposits (Singida region) and Bahi uranium deposits (Dodoma region) both in Central Tanzania [6]. These discoveries of uranium deposit at Mkuju in Ruvuma, Bahi in Dodoma and Manyoni in Singida have brought concern about the levels of natural radioactivity in soil, vegetations and in locally grown food crops at the areas in the neighbourhood of the deposits [7].

Green leafy vegetables are very prone to external contamination during their growing season [8]. Other vegetables, including root vegetables, may also become contaminated. In the early stages of fallout, green vegetables can be a very significant pathway for short lived radionuclides [8]. Therefore, it is important to obtain representative vegetable samples, and sampling should be planned carefully. The radioactivity levels play a vital role as they can be used for decision making in economic, legal or environmental management [1]. So far there is no information regarding radioactivity levels in leafy vegetables from the area of study (Manyoni) which have been established. Therefore this study aimed at establishing a baseline radioactivity levels in leafy vegetables in the selected area of study before the commencements of uranium mining and milling.

In the present work, radioactivity levels of U-238, Th-232, and K-40 in daily diets were determined in selected leafy vegetables from Manyoni. The obtained results were used for the estimation of annual intake of radionuclides and annual effective doses of these radionuclides in the adult population of Manyoni District, Tanzania.

2. MATERIALS AND METHODS

2.1 Description of the study area

Manyoni District is located in the central part of Tanzania as shown in figure 1. Its geographical coordinates are 5^0 45' 0" South, 34^0 50' 0" East. It has an area of 28,620 sq.km which is about 58 % of the entire of Singida region. The district has a population of 296,763 people [9]. The area under the study is mainly used for cultivation of different types of crops (like maize, sorghum, vegetables, and Pulses) and animal grazing. The area of study is with the Manyoni uranium project area, which extends from Bahi district in Dodoma region, the capital of Tanzania. The region incorporates an extensive closed draining system developed over weathered uranium rich granites. This drainage captures dissolved uranium leached from underlying rocks and transports it to suitable precipitation trap sites. The uranium targets in the area are described as calcrete-hosted uranium mineralization near to the surface and sandstone-hosted deposits within buried uvial channel systems [6].

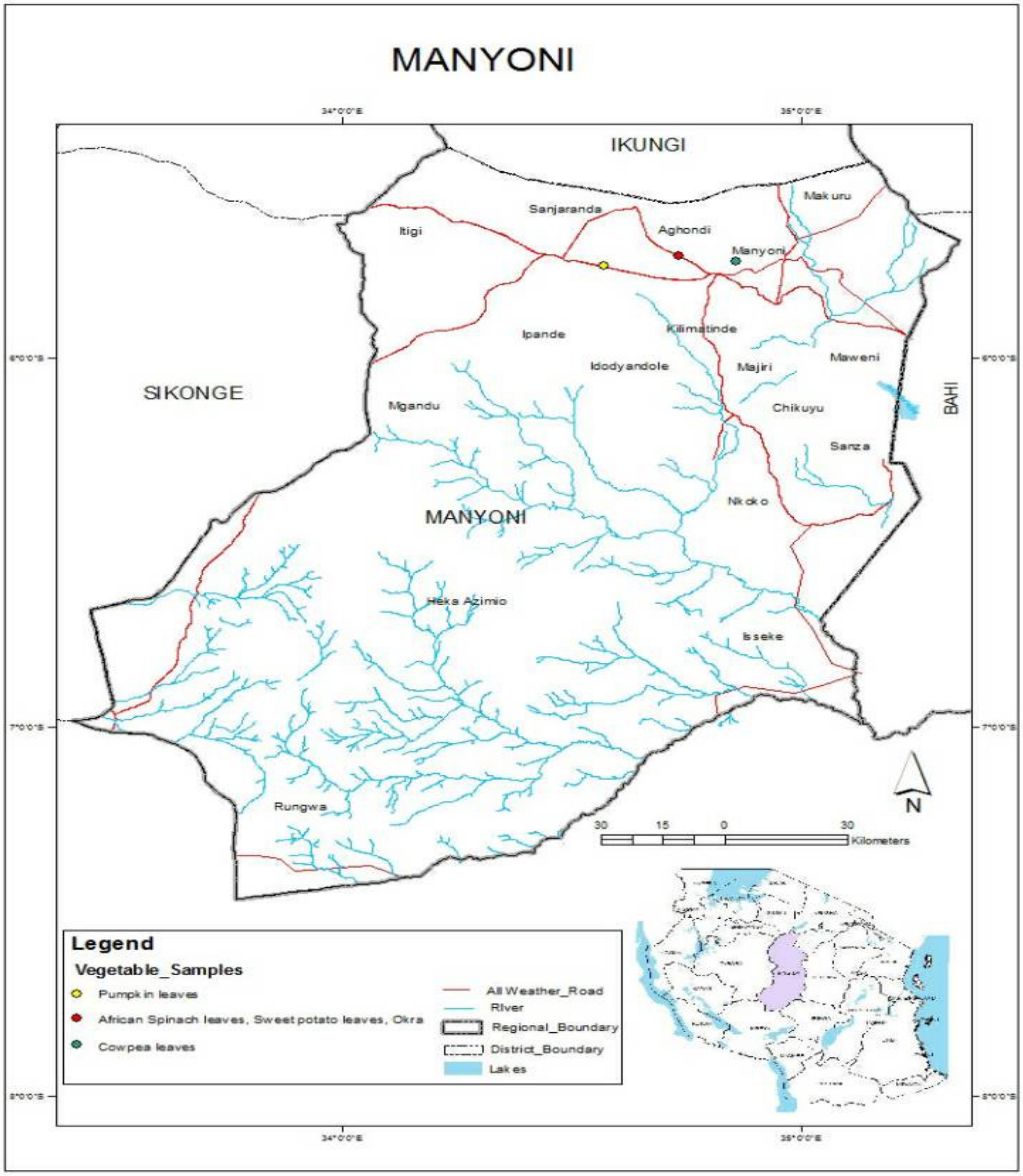

Figure 1: A map showing Manyoni District: The Insert shows its relative position in Tanzania

2.2 Sample collection and Preparation

The sampling was carried out during rainy season (between January and February). Thirty bunches of leafy vegetables were collected from the farmlands in selected areas in Manyoni district as shown in Table 1. The samples were washed with normal water, as for human consumption, weighed and chopped into small parts, oven dried at a temperature of 80℃ for 4 days, milled and sieved to collect the appropriate fractional mesh size**.** All the samples were packed in plastic (polyethylene) cylindrical containers of approximately 500 cm^3 volume and the containers were completely sealed for at least 4 weeks to allow radioactive equilibrium to be reached [2]. This step ensured that radon gas and its daughters remained in the sample. The table 1 indicates the type of samples and their place of origin.

Table 1: A list of various samples collected from different areas in Tanzania.

Sample ID	Sample name	Latitude	Longitude	Area
V1 (n=5)	African Spinach leaves (*Amaranthus ssp*)	S 05^0 41' 55.3"	E 34^0 44' 56.4"	kamenyanga
V2 (n=7)	Sweet potato leaves (*Ipomea batata*)	S 05^0 41' 55.3"	E 34^0 44' 56.4"	Kamenyanga
V3 (n=5)	Cowpea leaves (*Vigna unguiculata*)	S 05^0 42' 51.2"	E 34^0 52' 25.1"	Membeta
V4 (n=8)	Pumpkin leaves (*Curcubita moschata*)	S 05^0 43' 37.5"	E 34^0 35' 01.8"	Kitopeni
V5 (n=5)	Okra (*Abelmoschus esculentus*)	S 05^0 41’ 55.3”	E 34^0 44’ 56.4”	Kamenyanga

n= number of vegetable bunches

2.4 Instrumentation

The measurements were carried out at the Egyptian Second Research Reactor (ETRR-2). The gamma ray spectrometry technique was applied for determination of activity concentration in the vegetable samples. The radionuclides were determined by Compton suppression system, high-resolution gamma ray spectrometry using n-type HPGe detector Model GMP-100 250-S and Serial No. 38-N31278A coupled to a computer based PCA-MR 8192 Multi-Channel Analyzer (MCA) mounted in a cylindrical lead shield (100 mm thick) and cooled in liquid nitrogen. The detector has a relative efficiency of 100 % and resolution of 2.1 keV at 1.33 MeV of Co-60 line and a peak-to-Compton ratio of 64:1. The descriptions on the techniques used for energy and efficiency calibrations of the gamma-spectrometry system are well documented elsewhere [10, 11].

The specific radioactivity of K-40 was measured directly by its own gamma ray at 1460.8 keV (10.7), while activities of U-238 and Th-232 were calculated based on the weighted mean value of their respective decay products in equilibrium. The specific radioactivity of U-238 was measured using the 295.2 (18.2) keV gamma ray from Pb-214 and the 609.3 (44.6) keV gamma ray from Bi-214. While the specific radioactivity of Th-232 was measured using the 911.2 (26.6) keV from Ac-228, and the 583.2 (30.6) keV from TI-208. The values inside the parentheses following gamma-ray energy indicate the absolute emission probability of the gamma decay.

2.4.1 Activity Calculation

The activity (A) in Bq/kg of the radionuclides in the samples was calculated after decay correction using the expression below [8] and presented in Table 3.

$$A = \frac{N}{T_L P_\gamma \varepsilon M} \qquad 1$$

Where M is the dry-weight of sample (kg), N is the net Peak area for the sample in the peak range, P_γ is the gamma emission probability, T_L is the counting live time, and ε is the photo peak efficiency [12].

2.4.2 Detection Limit

Radioactivity measurements are characterized by a variable zero level due to background. This situation obliges one to work with detection and determination limits when the radioactivity of the source is very low. For the purpose of accuracy and reliability of data in gamma spectrometry it is necessary in the measurement process to introduce two specific levels:

i. Detection limit – indicates if an analytical process leads to a quantitative detection.
ii. Decision limit – that allows one to deduce whether the result of the analysis indicates that the sample is radioactive or not radioactive.

Due to the fact that the detection limit is not always significant, another parameter (L_D) was introduced, which is the lower limit of detection taking into account 95 % level of confidence as 5 % presence of real activity (false negative) and 5 % no real activity (false positive) [12, 13, 14]. L_D is given by the following expression:

$$L_D = 2L_C + 2.706 \rightarrow 2(2.326\,\delta_{NB}) + 2.706 \qquad 3$$

Where, L_C is a critical level above which the degree of confidence is acceptable for the net count. ($L_C = 2.326\ \delta_{NB}$).

$$L_D = 4.652\ \delta_{NB} + 2.706 \qquad 4$$

The minimum detectable activity (MDA) was then calculated using the formula below:

$$MDA = \frac{L_D}{\varepsilon\, T_L P_\gamma} \qquad 5$$

Whereby P_γ is the gamma emission probability, T_L is the counting live time; ε is the photo peak efficiency. The minimum detectable activity (MDA) of the γ-ray measurement system was calculated according to the equation 2 above [14]. The MDA for each radionuclide was calculated and summarized in the Table 2.

Table 2: The Minimum Detectable Activity (Bq/kg) of detected radionuclides at specific energies

Daughter nuclide	Energy(KeV)	MDA (Bq/kg)
Pb-214	295.22	0.42
Bi-214	609.32	0.45
Ac-228	911.20	0.73
Tl-208	583.19	0.18
K-40	1460.75	5.02

3. RESULTS AND DISCUSSION

3.1 Activity Concentration of Vegetables

The activity concentrations of the natural radionuclides of the Uranium and Thorium series and K-40 were investigated in the vegetables. The results obtained are shown in the Table 3. The total uncertainty value (Table 3) is composed of the random and systematic errors in all the factors involved in producing the final nuclide concentration result [15].

The radioactivity concentrations in selected vegetables ranged from 2.2 Bq/kg– 36.8 Bq/kg for U-238, 4.1 Bq/kg – 30.1 Bq/kg for Th-232, 700.0 Bq/kg – 2520.0 Bq/kg for K-40. As shown in figure 2, in all the vegetable samples, highest levels of U-238 were found in Cowpea leaves from Membeta followed by Pumpkin leaves from Kitopeni. Sweet potato leaves and Okra recorded lowest concentration of about 5.8 Bq/kg and 2.2 Bq/kg respectively. For Th-232, highest activity concentration levels were found in

Amaranthus and Pumpkin leaves from Kamenyanga and Kitopeni respectively. Sweet potato leaves from Kamenyanga occupied a third place. The lowest activity concentration of Th-232 was reported from Cowpea leaves from Membeta (Table 3).

Table 3: Activity concentration (Bq/kg) obtained in different analyzed samples

Name	Area	U-238	Th-232	K-40
African Spinach leaves (*Amaranthus ssp*)	Kamenyanga	19.7 ± 0.4	30.1 ± 0.9	2520.0 ± 50.5
Sweet potato leaves (*Ipomea batata*)	Kamenyanga	5.8 ± 0.5	12.4 ± 1.0	1660.0 ± 33.5
Cowpea leaves (*Vigna unguiculata*)	Membeta	36.8 ± 0.7	4.1 ± 0.6	700.0 ± 14.1
Pumpkin leaves (*Curcubita moschata*)	Kitopeni	30.8 ± 0.7	17.6 ± 1.1	2050.0 ± 41.2
Okra (*Abelmoschus esculentus*)	Kamenyanga	2.2 ± 0.3	6.5 ± 0.7	772.0 ± 15.6

The activity concentration of K-40 was found to be high in all vegetables. This can be attributed to the use of fertilizers in large extent affecting the radionuclides concentrations, especially potassium. But also the high value of K-40 may also be due to the soil origin and the nature of some vegetables.

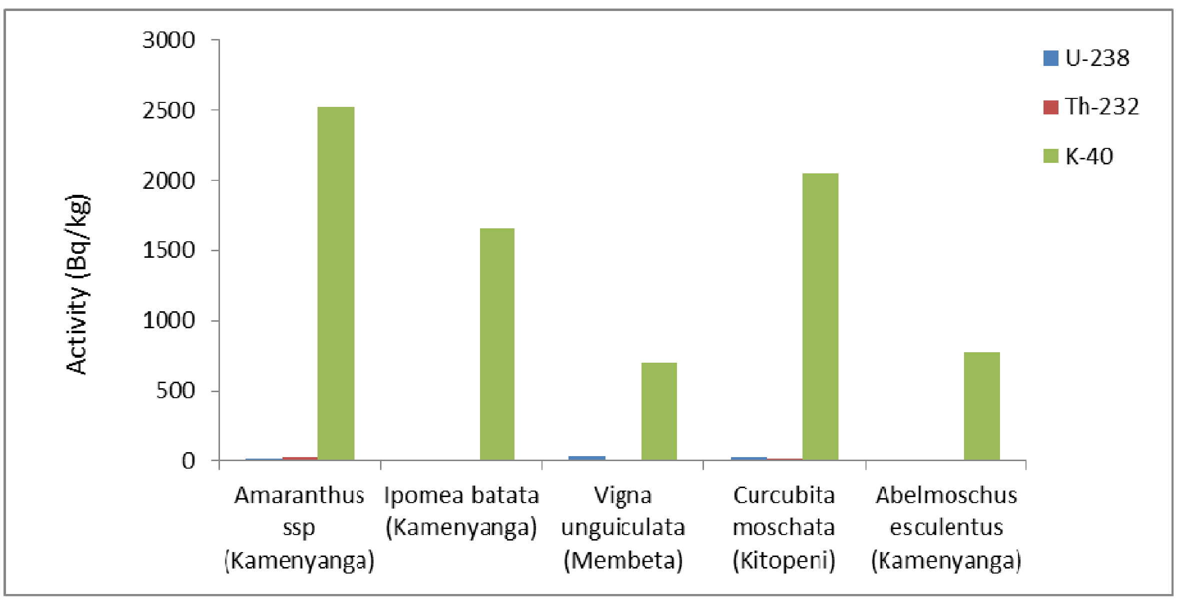

Figure 2: Activity Conc. (Bq/kg) in Vegetable from Manyoni

The activity concentrations of U-238, Th-232 and K-40 in vegetable samples found in this study were compared with studies of radioactivity in vegetable samples within the country (Tanzania) and from other countries as shown in Table 4.

Table 4: Comparison of activity concentration (Bq/kg) in leaf vegetables obtained in this study with that from different parts of Tanzania and around the World

Place / Location	Radionuclides			Reference
	U-238	Th-232	K-40	
TANZANIA (Manyoni)	22.2 – 36.8 (19.06)	4.06 – 30.1 (14.13)	700.0 – 2520.0 (1540.4)	Present Study
TANZANIA (Minjingu)	393	318	1568.0	[2]
TANZANIA (Iringa)	11.3 – 58.9 (29.6)	18.4 – 40.3 (27.8)	437 – 1281 (960)	[16]
SUDAN	0.51 – 3.42 (1.44)	9.04 – 11.06 (10.05)	43.97 – 211.24 (143.47)	[17]
NIGERIA	15.9	20.8	232	Adopted from Mohammed *et al.* [16]
CAMEROON	42	17	302	Adopted from Mohammed *et al.* [16]
IRAN	BDL – 6.99 (5.21)	2.22 – 10.56 (4.76)	108.99 – 319.21 (186.15)	Adopted from Mohammed *et al.* [16]
CHINA	16	23	-	[18]
POLAND	14 – 15	4 – 7	-	[18]
INDIA	61 – 72	-	-	[18]
JORDAN	0.6 – 2.6	0.7 – 3.4	698 – 1439	Adopted from Mohammed *et al.* [16]
USA	24	18	-	[18]
WORLD MEAN	35	30	400	[18]
REF VALUE	20	15	-	[18]

Mean activity of U-238 in vegetables from Minjingu and Iringa were higher by factors of 20 and 1.5 compared to that reported in Manyoni. The reason for this difference is that, soils from Minjingu are contaminated due to presence of active phosphate mine and deposit [2, 3] also farmers from Iringa use phosphate fertilizers [16]. When compared with activities from other countries, the activity of U-238 from Manyoni was higher than that reported from Jordan, Poland and Iran (Table 4). U-238 levels in vegetables from Manyoni were lower than the values reported from India and United States (Table 4). However, it was within the reference value of 20 Bq/kg [18].

The mean activity of Th-232 reported in vegetables from Minjingu and Iringa both in Tanzania were higher by folds of 22 and 2 when compared to that of this study. When compared with the mean activity levels from other countries, the activity of Th-232 from this study was higher than the levels reported in vegetables from Sudan, Iran, Poland and Jordan (Table 4). The reported mean activity of Th-232 from this study is much lower than the mean activity reported from United States and the World average as well. However it was almost the same as the reference value of 15 Bq/kg [18].

Mean activity of K-40 in vegetables from this study was almost the same as that reported in edible vegetation from Minjingu. The presence of phosphate mine and deposit in Minjingu as well as the uranium deposit in Manyoni might be the reason. However, the mean activity of K-40 from this study was much higher than the mean activities of K-40 reported in literature reviewed into this study. High concentration of K-40 in food is attributed to its concentration in the soils. The concentrations of K-40 in the soils may be associated with the geological properties of the area [19].

3.2. Calculation of the Annual Effective Dose

The annual effective ingestion dose due to vegetables consumption depends on the vegetables consumption rate and radioactivity in the vegetables [3, 7]. Calculation of the annual effective dose due to the ingestion of vegetables was performed based on the metabolic model developed by the International Commission of Radiological Protection (ICRP) [20]. The effective dose from a radionuclide in vegetables can be determined by the equation below [3, 7].

$$E_{(\tau)_{ing,p}} = D_{ing} F_p C_{p,i} \qquad 6$$

Where $E_{(\tau)\ ing,\ p}$ is the annual effective dose by ingestion of the radionuclide *i* in vegetable *p* (mSv/year), D_{ing} is the dose coefficient (dose conversion factor) by ingestion of radionuclide *i* (mSv Bq^{-1}) given by ICRP [20], which varies with both radionuclides and the age of individuals. $C_{p,\ i}$ is the concentration of nuclide *i* in the ingested vegetable *p* at the time of consumption (Bq/kg) and F_p is the consumption rate for vegetable *p* (kg/year). Dose calculations are based on the assumption described in Table 5.

It was not possible to compute the vegetables consumption rate because, in Tanzania during the rainy season, vegetables are usually consumed daily to several times a week, while during the dry season frequency of consumption spans from once a week to several times a week [21]. Therefore, the consumption rate of 40 kg/person/year given by FAO was adopted [22]

Table 5: Dose conversion factors and Vegetable consumption rate in Tanzania

Radionuclide	Dose conversion factor (Sv/Bq)	Vegetable Consumption rates (Kg/person/year) [22]
U-238	4.5 E-08	40
Th-232	2.3 E-07	
K-40	6.2 E-09	

The annual effective ingestion doses due to intake of radio-nuclides are shown in Tables 6 and 7. Results show that the total effective ingestion dose due to annual intake of U-238, Th-232 and K-40 from vegetables was 2.73 mSv/year of which 1.91 mSv/year was from K-40 and 0.82 mSv/year was from U-238 and Th-232 (Table 7).

According to a report by UNSCEAR [23], the total exposure per person resulting from ingestion of terrestrial radionuclides should be less or equal to 0.29 mSv/year, of which 0.17 mSv/years is from K-40 and 0.12 mSv/year is from thorium (Th-232) and uranium series (U-238). The total annual effective ingestion dose due to intake of vegetables was 2.73 ± 0.08 mSv/year which was found 9.4 times higher than world safe value of total exposure per person resulting from the ingestion of terrestrial radionuclides (Table 7). The dose value is also higher than the annual dose limit of 1 mSv/year recommended by the ICRP for the general public [20].

Table 6: Mean activity (Bq/kg) and Annual effective dose (Sv/year) due to intake of radionuclides from vegetables

Name	Radionuclide	Activity (Bq/kg)	Annual effective dose (mSv/year)
African Spinach leaves (*Amaranthus ssp*)	U-238	19.7 ± 0.42	0.036 ± 0.001
	Th-232	30.1 ± 0.89	0.277 ± 0.008
	K-40	2520.0 ± 50.54	0.625 ± 0.013
Sweet potato leaves (*Ipomea batata*)	U-238	5.76 ± 0.49	0.011 ± 0.001
	Th-232	12.4 ± 1.04	0.114 ± 0.009
	K-40	1660.0 ± 33.45	0.412 ± 0.008
Cowpea leaves (*Vigna unguiculata*)	U-238	36.8 ± 0.65	0.066 ± 0.001
	Th-232	4.06 ± 0.62	0.037 ± 0.006
	K-40	700.0 ± 14.13	0.174 ± 0.004
Pumpkin leaves (*Curcubita moschata*)	U-238	30.84 ± 0.68	0.056 ± 0.001
	Th-232	17.6 ± 1.08	0.162 ± 0.010
	K-40	2050.0 ± 41.17	0.508 ± 0.010
Okra (*Abelmoschus esculentus*)	U-238	2.22 ± 0.33	0.004 ± 0.001
	Th-232	6.49 ± 0.67	0.060 ± 0.006
	K-40	772.0 ± 15.55	0.191 ± 0.004

Table 7: Contribution of each nuclide in annual effective dose (mSv/year)

Radionuclide	Annual Effective doses		Allowable Limits [23]
U-238	0.173 ± 0.005	0.823 ± 0.044	**0.12**
Th-232	0.650 ± 0.039		
K-40	1.910 ± 0.039	1.910 ± 0.039	**0.17**
Total Annual Effective Dose	2.733 ± 0.083	2.733 ± 0.083	**0.29**

3.3 Calculation of annual intake of radionuclides

For the annual radionuclide intake evaluation, the weighted average for each radionuclide in each vegetable category (ω) was calculated, and then multiplied by the respective consumption rate (F_p), and then presented in Table 8 and compared with the allowable limits.

$$D_{intake,\, i} = \omega \times F_p \qquad 7$$

Table 8: The estimated annual intake of radionuclides (Bq) via ingestion of vegetables

Radionuclide	Weighted average radioactivity (ω) (Bq/kg)	Estimated Daily Intake (Bq)	Estimated Annual Intake (Bq)	Allowable Annual Intake of nuclides (Bq) [18]
U-238	19.06 ± 0.51	2.09 ± 0.06	762.9	5.7
Th-232	14.13 ± 0.86	1.55 ± 0.09	565.8	1.7
K-40	1540.40 ± 30.97	168.8 ± 3.39	61612.0	-

The estimated annual intake of nuclide especially U-238 and Th-232 were higher than the allowable annual intake of radionuclides as shown in Table 8. The estimated annual intake values were much higher compared to the annual intake of U-238 and Th-232 reported from China, Germany, India and United States of America [18].

4. CONCLUSION

A radiological study was performed to determine the radioactivity levels in vegetables and the annual effective dose of natural radionuclides (U-238, Th-232 and K-40) into human body due to intake of vegetables from Manyoni District, Central part of Tanzania. The radioactivity concentrations in vegetable samples were higher than the world average value. The annual effective ingestion dose to human body due to intake of vegetables was also found 9.4 times higher than the world safe value of total exposure per person resulting from the ingestion of terrestrial radioisotopes. The annual intakes of radionuclides (U-238 and Th-232) were much higher than the allowable annual intake. However, the total annual effective dose and annual intake of radionuclides calculated in this work might be overestimated. This is because; the vegetable consumption rate was not specifically drawn from the study area. The consumption rate used is the representative of the whole country (Tanzania) and assumed that the vegetables are available throughout the year, while in the study area, during the rainy season, vegetables are usually consumed daily to several times a week, and during the dry season frequency of consumption spans from once a week to several times a week. This study aimed to establish a baseline database, the results can be used as reference information to assess any changes in the radiological background levels due to any geological and physical processes that may occur in future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nyanda P.B. Identification and Quantification of Radioactivity levels and design a database for environmental radioactive samples in Tanzania. M.Sc in Nuclear Science and Technology Dissertation, University of Alexandria, Egypt. 2012.
2. Banzi, F.P., Kifanga, L.D., Bundala, F.M., Natural radioactivity and radiation exposure at Minjingu phosphate mine in Tanzania. Journal of Radiological Protection 20, pp 41-51, 2000.
3. Nkuba L.L and Mohammed N.K. Determination of radioactivity in maize and mung beans grown in the neighbourhood of Minjingu Phosphate mine, Tanzania. Tanzania Journal of Sciences. Vol 40, pp 51-59, 2014.
4. Harb, S. Natural Radioactivity Concentration and Annual Effective Dose in Selected Vegetables and Fruits. Journal of Nuclear and Particle Physics 2015, 5(3): 70-73 DOI: 10.5923/j.jnpp.20150503.04
5. Mantra EIS. Mantra Tanzania Limited Environmental Impact Statement for the Proposed Uranium Mining Project at Mkuju River Project, Namtumbo. 2010; 1. Final Report.
6. Uranex. New Uranium Mineralization Discovered at Manyoni; 2010. Available:www.infomine.com/index/pr/Pa872980.PDF
7. Nkuba L.L and Sungita Y.Y. Radioactivity Levels in Maize from High Background Radiation Areas and Dose Estimates for the Public in Tanzania. *Physical Science International Journal 13(3): 1-8, 2017; Article no.PSIJ.31697;* DOI: 10.9734/PSIJ/2017/31697.
8. IAEA. Measurement of radionuclides in food and the environment. *Technical Report series.* No. 295, Vienna: Austria, 1989.
9. United Republic of Tanzania. United Republic of Tanzania Population and Housing Census (PHC). 2012.
10. IAEA. Radioactive fallout in food and agriculture. IAEA-TECDOC-494. IAEA, Vienna; 1989.
11. Knoll FG. Radiation detection and measurement. 3rd Edition, John Wiley & Sons, Inc., USA; 2000.
12. HPGe Detectors for Compton suppression counting systems- ANSI/IEEE-3-255-1996.
13. Commission of the European Communities. Underlying data for derived emergency reference levels. Post Chernobyl-action (J. Sinnaeve and G. Gerber .eds.). EUR 12553 (1991).
14. El Afifi, E.M., M.A. Hilal, S.M. Khalifa and H.F. Aly. Evaluation of U, Th, K and emanated radon in some NORM and TENORM samples. Radiat. Meas., 41: 627-633. 2006.

15. International Standards Organization (ISO/IEC 17025:1999), European Committee for Standardization, Brussels, 1999.
16. Mohammed N.K, Chanai E and Alkhorayef M. The impact of the extensive use of phosphate fertilizers on radioactivity levels in farm soil and vegetables in Tanzania. J. Radioanal Nucl Chem (2016) 307:2373–2379. DOI 10.1007/s10967-015-4377-X.
17. Hatem E. F. H. Radioactivity levels of basic foodstuffs and dose estimates in Sudan. M.Sc Thesis, Sudan Academy of Sciences (SAS), Atomic Energy Council (2009).
18. Fisenne, I.M. Tutorial session 4. Long lived radionuclides in the environment, in food and in human beings. p. 185- 255 in: Fifth International Symposium on the Natural Radiation Environment. Tutorial Sessions. EUR 14411 EN (1993)
19. Saidou F.O, Baechler S, Moise K.N, Merlin N and Froidevaux P. Natural radioactivity measurements and dose calculation to the public: Case of uranium-bearing region of Poli in Cameroon. *Journal of Radiation Measurement.* Doi: 10.1016/j.radmeas; 2010.
20. ICRP International Committee of Radiological Protection. Age dependent doses to members of public from intake of radionuclides: compilation of ingestion and inhalation coefficients. ICRP publication 72 (Elsevier Science) (1996).
21. Weinberger, K and Msuya, J. Indigenous Vegetables in Tanzania-Significance and Prospects. Shanhua, Taiwan: AVRDC-The World Vegetable Center, Technical Bulletin No. 31, AVRDC Publication 04-600. 70 pp. ISBN 92-9058-136-0; 2004
22. Chauvin N.D, Mulangu F and Porto G. Food Production and Consumption Trends in Sub-Saharan Africa: Prospects and Transformation of Agricultural Sector. UNDP Regional Bureau for Africa, Working Paper 2012-011.
23. UNSCEAR. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York. 2000