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Natural radioactivity levels and estimation of radiation exposure from soils in Bahi and Manyoni Districts in Tanzania

Leonid L. Nkuba[1*] and Pendo B. Nyanda[1]
[1] *Tanzania Atomic Energy Commission, Directorate of Radiation Control*
P.O Box 80479, Dar es Salaam, Tanzania
**Corresponding author: leonid_nkuba@yahoo.co.uk*

ABSTRACT

Soils from Bahi and Manyoni disticts in Tanzania were analyzed for radioactivity. The radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K were measured by direct γ-ray spectrometry using HPGe detector by Compton suppression method. The radioactivity concentration in soil were computed in arithmetic mean. The results from this study have been compared with those from other areas in Tanzania, different countries of the world and the world average radioactivity in the soil. To assess the radiological effects and hazards indices from natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K), the absorbed dose rate (*DR*), the annual effective dose equivalent (*AEDE*), Excess Lifetime Cancer Risk (*ELCR*), the radium equivalent activity (*Raeq*), the external (*Hex*), the alpha index (*Iα*) and the radioactivity level index (*Iγ*) were calculated. Except for DR in all the soil samples; Raeq, Hex and Iα exceeds the recommended limits due to high activity of ^{226}Ra in Membeta soils. Also Iγ was above the limits due to higher ^{226}Ra in soils from Membeta and ^{232}Th in Ilindi and Nala. Whilst the other radiological parameters (AEDE and ELCR) as well as the Raeq, Hex, Iα and Iγ in same areas were far below the recommended limits. However, this does not guarantee the safety. Therefore the probability of occurrence of the health effects from radiation is significant. The study recommends that the soils from Membeta should not be used as building material because they might expose the population to radiation.

Keywords: Uranium deposit; Soils; Radioactivity; Radiological hazards/indices or effects

1. INTRODUCTION

The radioactivity level from the natural radionuclides is known as background radiation and it is a source of continuous exposure to human beings and his environment. The background radiation can be elevated if the environment is polluted either from man-made or natural activities. It can also be high in regions with deposit of mineral resources such as uranium ores and phosphate. In Tanzania, the uranium exploration and feasibility studies have found several sites in Manyoni and Bahi with economically viable uranium deposit [1]. These discoveries brought concerns to public residing in nearby villages. The concerns are mainly on the natural radioactivity in soils at areas in the neighbourhood of the deposit and radiological health hazards which are associated with uranium deposit and the exploration activities. This is because there are reports in the literature which indicate high radioactivity levels in regions near uranium deposits [2].

The amount of radioactivity in soil varies widely; hence studies worldwide have measured the activity concentration of natural radionuclides in soil to ascertain the levels of contamination and to assess the essential radiological information [3]. Therefore, this study aimed at estimating the activity concentration of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil collected from three areas at Bahi and four areas at Manyoni Districts in Tanzania and to evaluate the radiological indices and their hazards or effects on the population who live in or around the area. The data from this study will offer useful and necessary information in the monitoring of environmental contamination which will provide appropriate and better protection guidelines to the public.

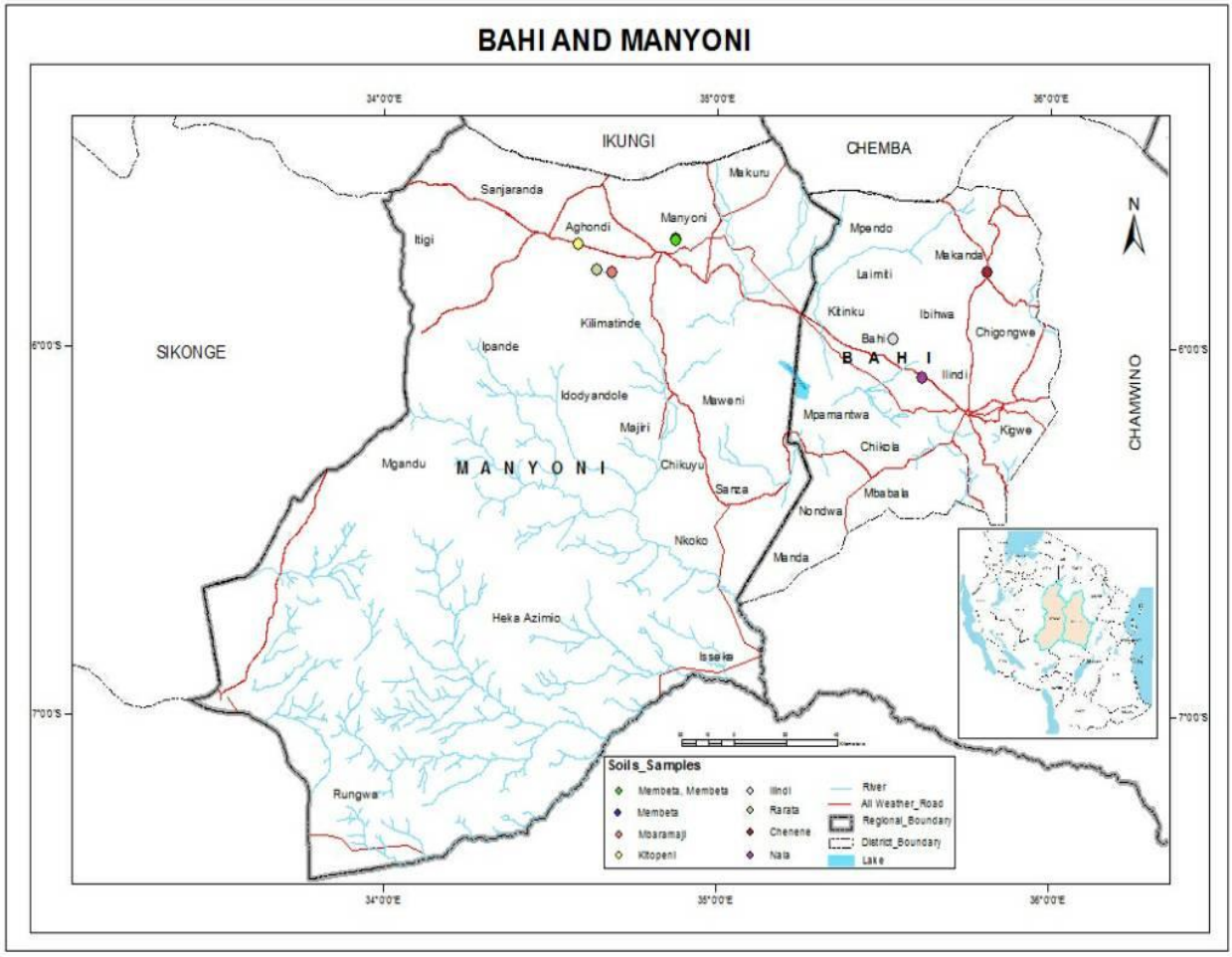
2. MATERIALS AND METHODS

2.1 Description of Study Area

Manyoni and Bahi are two adjacent districts found in central of Tanzania (Figure 1). Manyoni District is located in the central part of Tanzania. Its geographical coordinates are 5^0 45' 0" South, 34^0 50' 0" East. It has an area of 28,620 km^2 with population of 296,763 people [4]. Bahi district is located at 5^0 57' 10" South, 34^0 50' 43" East. It has an area of 5,448.4 km^2 with population of 221,645.

The areas of study 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 [1].

Figure 1: A map showing the study area (Bahi and Manyoni)



2.2 Sample collection and Preparation

A total of 16 soil samples of about 2 kg each were randomly collected from 3 different areas of Bahi and 5 different areas of Manyoni Districts using the standard sampling procedures [5]. The areas

are: Ilindi (2 samples), Chenene (2 samples), Nala (2 samples), Rarata (2 samples), Mbaramaji (2 samples), Kitopeni (2 samples) and Membeta (4 samples). Samples were collected in during rainy season (between January and February). Soil samples were taken within an area of 4 m^2 near the drill holes where soil samples were taken by foreign company for Uranium exploration.

As shown in Figure 1, with the use of coring tool, the first surface soil sample was collected at the depth level between 0 -15 cm [6], whilst the second soil sample was drawn at a depth of 15-30 cm from the surface at the same location. This depth (0 -30 cm) was choosen as it is almost the same as the depth of plough line [5]. The collected samples were then placed in labeled polyethylene bags and transferred to the laboratory for preparation and analysis. In the laboratory, soil samples were oven-dried at the temperature of 105º C for 3 and 4 hours until the moisture was completely removed [7]. The samples were then ground into fine particles and thoroughly mixed and pass through a fine mesh sieve (~2 mm) to obtain composite representative samples [7]. Finally, the samples were packed into 500 ml marinelli beakers, which were well sealed using silicon and plastic tapes for air tight for about 30 days in order to allow secular equilibrium between ^{226}Ra and its short-lived decay products in the ^{238}U series.

2.3 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 soil 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 ^{60}Co 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 [5, 8].

The specific radioactivity of ^{40}K was measured directly by its own gamma ray at 1460.8 keV (10.7), while activities of ^{226}Ra and ^{232}Th were calculated based on the weighted mean value of their res-

pective decay products in equilibrium. The specific radioactivity of ^{226}Ra was measured using the 295.2 (18.2) keV, 351.9 (35.1) keV gamma rays from ^{214}Pb and the 609.3 (44.6) keV, 1764.5 (15.1) keV from ^{214}Bi. The specific radioactivity of ^{232}Th was measured using the 911.2 (26.6) keV from ^{228}Ac, and the 583.2 (30.6) keV from ^{208}Tl. The values inside the parentheses following gamma-ray energy indicate the absolute emission probability of the gamma decay.

2.3.1 Minimum Detectable Acticivty (MDA)

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. The minimum detectable activity (MDA) of the γ-ray measurement system was estimated for each radionuclide as proposed by Knol [8] and summarized in subsection 3.1.

2.3.2 Activity Calculation

The activity concentartion (A) in Bq/kg of the radionuclides in the soil samples was calculated after decay correction using the expression below [9] and presented in Table 1.

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

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 Ɛ is the photo peak efficiency [10].

2.4 Radiological Effects

The activity levels of natural radiations have been represented by a single quantity to estimate the radiological hazard or effect and consequently the environmental impacts of radiations [11, 12]. Among several radioactive nuclides, ^{226}Ra is often chosen in the majority of the published papers concerned with the environmental radiation studies. This is attributed to the fact that ^{226}Ra is more chemically active and it is similar to actinium. Therefore, it can be absorbed from the soil by plants and transported to food chain to human. The radiation emitted by ^{226}Ra affetcs the tissues in the

bone marrow and hence can cause cancer. Also the radioactivie gas ^{222}Rn (an alpha emitter and daughter of ^{226}Ra) and the irradiation of lungs still a matter of concern regarding the public health. About 98.5% of the radiological effects of the ^{238}U series are produced by radium and its daughters. Therefore, any disequilibrium between ^{238}U and ^{226}Ra has no effect on the dose estimation from the measurement of ^{226}Ra, and the dose rates derived from ^{226}Ra are usually presented as that of ^{238}U.

2.4.1 Absorbed dose rate in air (DR)

The outdoor external absorbed dose rate (DR) in air at 1m above the ground surface to the population is calculated from the activities of the Ra, Th and K radionuclides. It is defined as [12]

$$DR = CRa * ARa + CTh * ATh + CK * AK \quad (2)$$

Where DR is outdoor external absorbed dose rate in nGy/h, ARa, ATh and AK are the activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K respectively. CRa, CTh and CK are the conversation factors in nGy/h per Bq/kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The values are CRa = 0.4368, CTh = 0.5993 and CK = 0.0417 [13].

2.4.2 Annual effective dose equivalent (AEDE)

The annual effective dose equivalent (*AEDE*) to the population can be calculated using the conversion coefficient from absorbed dose in air to effective dose (0.7 Sv/Gy), the outdoor occupancy factor 0.2 and the indoor occupancy factor 0.8 [12]. The indoor to outdoor ratio is 1:4. Also, its estimation depends on the assumption that the annual average time for exposure to radiation is 8760 hours (365.25d x 24h). Therefore, the annual effective doses equivalent for outdoors and indoors are calculated by using the relations [14].

$$D_{out}\ (Sv/y) = [Dr\ (nGy/h) \times 24h \times 365.25d \times 0.2 \times 0.7\ (Sv/Gy)] \times 10^{-6} \quad (3)$$

$$D_{in}\ (Sv/y) = [Dr\ (nGy/h) \times 24h \times 365.25d \times 0.8 \times 0.7\ (Sv/Gy)] \times 10^{-6} \quad (4)$$

This calculation takes into account that the people spend 20 % of their time outdoors and 80 % of their time indoors. The recommended values of AEDE are 20 mSv/y for the occupational members

and 1 mSv/y for the public [14, 15]. The corresponding worldwide values of D_{out} and D_{in} and the total dose (D_{tot}) are 0.08, 0.42 and 0.50 mSv/y, respectively [12].

2.4.3 Excess Lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk is calculated using below equation [16], and shown in Table 3.

$$\text{ELCR} = \text{AEDE}\ (\mu\text{Sv/y}) \times \text{DL (years)} \times \text{RF}\ (\text{Sv}^{-1}) \quad (5)$$

Where, *AEDE*, *DL* and *RF* are the total annual effective dose equivalent (in μSv/y), duration of life (70 years) and risk factor (Sv^{-1}), fatal cancer risk per Sievert. For stochastic effects, ICRP 60 uses values of 0.05 for the public [17]. The range of *ELCR* is 0.70×10^{-3} to 1.33×10^{-3} with an average of 0.95×10^{-3}.

2.4.4 Radium equivalent activity (Ra_{eq})

The distribution of ^{226}Ra, ^{232}Th and ^{40}K in any concerned sample is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity in Bq/kg to compare the specific activity of materials containing different amount of Ra, Th and K [11]. This activity index provides a useful guideline in regulating the safety standards on radiation protection for the general public residing in the area under investigation. It is defined as:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (6)$$

Where A_{Ra}, A_{Th} and A_K are activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K respectively. The maximum value of this index must be < 370 Bq/kg for keeping the external dose < 1.5 m Gy/y [11].

2.4.5 External hazard index (Hex)

The radium equivalent activity was modified by other quantity index named as the external hazard index [11]. This index measures the external hazard due to gamma-radiation and is defined as:

$$H_{ex} = A_{Ra} / (370\text{Bq/kg}) + A_{Th} / (259\text{Bq/kg}) + A_k / (4810\text{Bq/kg}) \leq 1 \quad (7)$$

Where H_{ex} is the external hazardous index and A_{Ra}, A_{Th} as well as A_K are the specific activities (Bq/kg) of radium, thorium and potassium, respectively. The value of this index must be lower than unity in order to keep the radiation hazard insignificant. This is the radiation exposure due to the radioactivity from a construction material, limited to 1.5 mGy/y. The maximum values of H_{ex} equal to unity correspond to the upper limit of Ra_{eq} (370 Bq/kg) [11].

2.4.6 Alpha index (I_α)

In addition to the external irradiation, radon and its short-lived products are also hazardous to respiratory organs. The alpha indices have been proposed to assess the exposure level due to radon inhalation originating from building material [18]. The internal exposure to radon and its daughter products are quantified by the Alpha index (I_α). This index is given by the following equation [19].

$$I_\alpha = A_{Ra} / 200 \text{ Bq/kg} \quad (8)$$

Where A_{Ra} is the activity concentration of ^{226}Ra in Bq/kg assumed in equilibrium with ^{238}U. The safe use of materials in building construction requires I_α to be less than 1. This limit corresponds to the ^{226}Ra concentration of 200 Bq/kg for building construction [20].

2.4.7 Radioactivity level Index ($I\gamma$)

This index is used to estimate the level of radiation risk, especially γ -rays, associated with natural radionuclides in builing material (i.e Soils). It is defined as [16]

$$I\gamma \text{ (Bq/kg)} = (A_{Ra}/150+A_{Th}/100+A_K/1500) \leq 1 \quad (9)$$

Where A_{Ra}, A_{Th}, A_k are the activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively. The value of $I\gamma$ must be less than unity in order to keep the radiation hazard insignificant. According to the European committee, this index is derived for identifying whether a dose criterion is met. The index is correlated with the annual dose due to the excess external gamma radiation caused by superficial material. The value of $I\gamma \leq 0.5$ corresponds to absorbed gamma dose rate less or equal to 0.3 mSv/y, while the $I\gamma \leq 1$ corresponds to absorbed gamma dose rate less or equal to 1 mSv/y [16].

3. RESULTS AND DISCUSSION

3.1 Minimum Detectable Activity (MDA)

The minimum detectable activities (MDA) for each radionuclide were as follows- for ^{214}Pb (295.22 keV) is 0.42 Bq/kg, for ^{214}Bi (609.31 keV) is 0.45 Bq/kg, for ^{228}Ac (911.20 keV) is 0.73 Bq/kg, for ^{208}Tl (583.19 keV) is 0.18 Bq/kg and ^{40}K (1460.81 keV) is 5.02 Bq/kg. As shown in Table 1, there were no soil sample reported to have activity level below the minimum detection limit (MDL).

3.2 Radioactivity in Soils

The radioactivity concentration levels of ^{226}Ra and ^{232}Th decay series, and ^{40}K were investigated in the soil samples. The results of radioactivity concentration levels of ^{226}Ra (^{238}U daughter), ^{232}Th and ^{40}K in soil samples from different locations of the study area are presented in Table 1. The results shows that the average radioactivity concentration in soil samples ranged from 10.80 Bq/kg – 835.00 Bq/kg for ^{226}Ra, 12.30 – 105.00 Bq/kg for ^{232}Th and 47.20 Bq/kg – 808.00 Bq/kg for ^{40}K. As shown in Figure 2, it can be noticed that the measured activity levels of natural radionuclides (^{226}Ra and ^{232}Th) in soil samples from this study exceed the world average activity while that of ^{40}K were found to be within the world average [12]. This is because the areas of the present study are found within the uranium deposit.

Figure 2: The activity conc. in soils from Bahi and Manyoni and that of world average

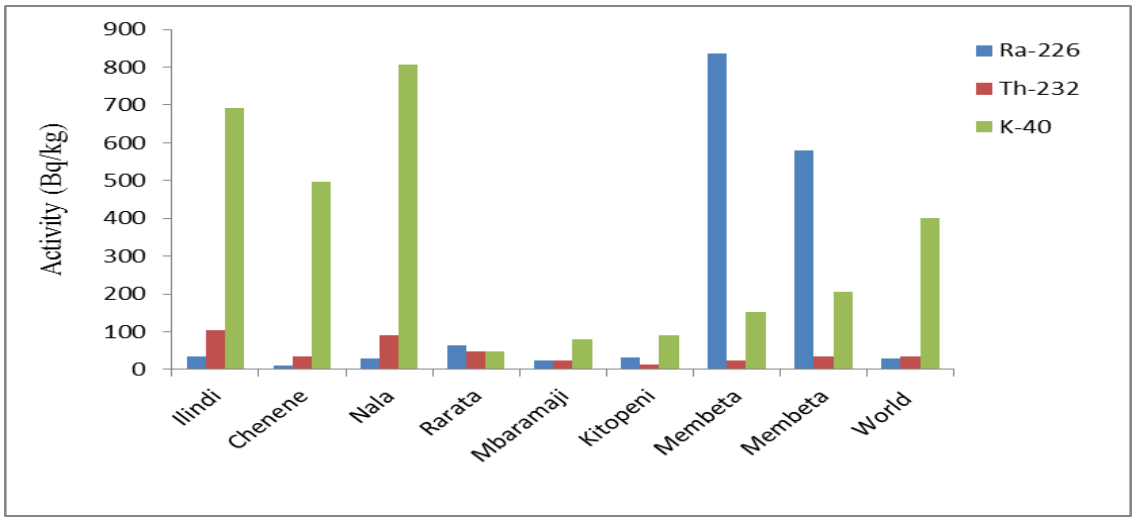


Table 1: Activity concentration (Bq/kg) in the soil sample from Bahi and Manyoni

District	Area & Number of Soil samples	Activity (in Bq/kg)		
		^{226}Ra	^{232}Th	^{40}K
Bahi	Ilindi (n=2)	33.7 ± 0.57	105.0 ± 2.16	692.0 ± 13.90
	Chenene (n=2)	10.8 ± 0.23	35.3 ± 0.78	496.0 ± 9.95
	Nala (n=2)	30.6 ± 0.49	90.5 ± 1.86	808.0 ± 16.18
Manyoni	Rarata (n=2)	63.2 ± 0.93	49.1 ± 1.03	47.2 ± 1.23
	Mbaramaji (n=2)	23.2 ± 0.38	24.8 ± 0.57	81.1 ± 1.79
	Kitopeni (n=2)	32.5 ± 0.49	12.3 ± 0.36	90.8 ± 1.91
	Membeta (n=2)	835.0 ± 11.87	24.8 ± 0.57	151.0 ± 3.30
	Membeta (n=2)	580.0 ± 8.24	33.8 ± 0.89	205.0 ± 4.36

As shown in Figure 2, the lowest mean value of ^{226}Ra was found in samples from Bahi (Chenene). The samples from Manyoni (Membeta) had the highest concentrations of ^{226}Ra, which were each 77 and 54 times higher than their values determined in samples from Bahi (Chenene). Soil samples from the Bahi had the highest mean value of ^{232}Th when compared to the soils from Manyoni. For instance, soils samples from Bahi (Ilindi) was 8.5 times higher than the mean value obtained in samples collected from Manyoni (Kitopeni). The activity of ^{40}K was reported in higher amount in soils from Bahi (Ilindi, Chenene and Nala) than in soils from Manyoni. The reason for this difference is that, soils sample from Bahi were collected from farms where the application of fertilizers is expected, whilst the soils from Manyoni were sampled from undisturbed soils.

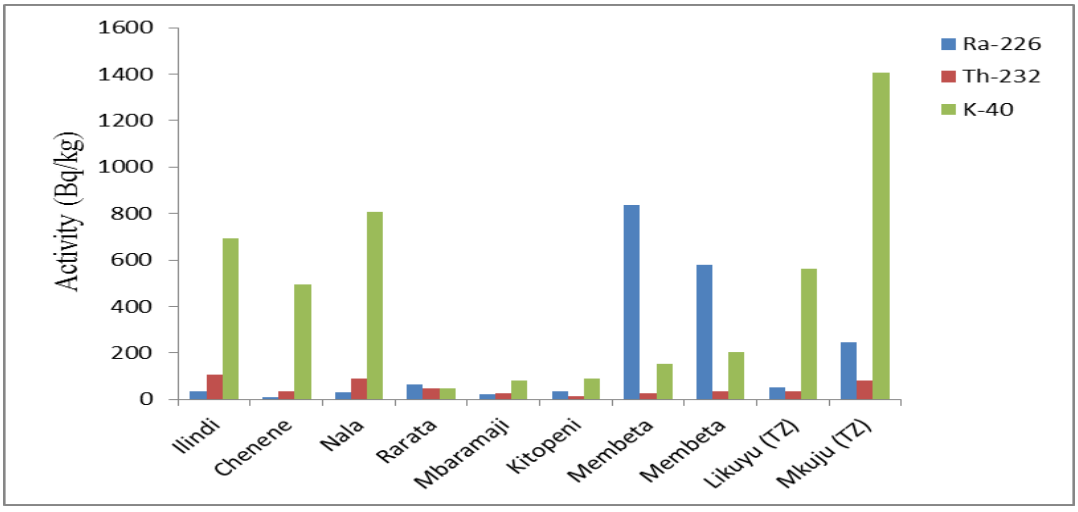
As shown in Table 2 and Figure 3, the concentration of ^{226}Ra from Likuyu village (Ruvuma) were higher compared to that from Bahi by folds of 1.5 to 4.8, while were in the same range to the activity of ^{226}Ra reported from Manyoni (Membeta) [21]. ^{40}K in soils from Bahi had higher activity than that of Likuyu, while the soils from Likuyu had higher activity of ^{40}K compared to that of Manyoni. Bahi, Manyoni and Likuyu village are located in the uranium deposit zones, the difference in activity of natural radionuclides might be influenced by geological structure of the underlying rocks. Moreover, except the concentrations of ^{226}Ra in soils from Membeta (Manyoni), the activity levels from this study fall within the range of other published results mentioned in Table 2.

The soils samples were collected during rainy season; hence the radionuclide concentrations that were measured would be probably not different in the dry season, because these natural radionuclides are most contented in the mineral or organic matrix.

Table 2: Radioactivity levels in soil and the absorbed dose in air (DR) at different Locations of Bahi & Manyoni districts with those from Mkuju and Likuyu and in other countries

Country	**Activity** (Bq/kg)			**Dose rate** (nGy/h)
	^{226}Ra (^{238}U)	**^{232}Th**	**^{40}K**	
Present Study (Mean)	10.8 – 835	12.3 – 105	47.2 – 808	25.9 - 385.97
Tanzania(Likuyu) [21]	52	36	564	--
Tanzania (Mkuju) [22]	245 (123 – 316)	80 (39 – 114)	1407 (1169 – 1651)	--
Malaysia [12]	67 (38 – 94)	82 (63 – 110)	310 (170 – 430)	92 (55 – 130)
China [12]	32 (2 – 440)	41 (1 – 360)	440 (38 – 760)	62 (2 – 340)
Egypt [12]	17 (5 – 64)	18 (2 – 96)	320 (29 – 650)	47 (14 – 118)
India [12]	29 (7 – 81)	64 (14 – 160)	400 (38 – 760)	56 (20 – 110)
Poland [12]	26 (5 – 120)	21 (4 – 77)	410 (110 – 970)	45 (18 – 97)
Nigeria [12]	14 (9 – 18)	19 (1 – 38)	896 (712 – 1098)	--
Japan [12]	33 (6 – 98)	28 (2 – 88)	310 (15 – 990)	55 (21 – 77)
USA [12]	40 (8 – 160)	35 (4 – 130)	370 (100 – 700)	47 (14 – 118)
World Average [12]	30 (16 – 110)	35 (11 – 64)	400 (140 – 850)	55 (18 – 93)

Figure 3: Activity concentration from this study with those from Likuyu and Mkuju (TZ)



3.3. Estimation of Radiation Hazards

The radiation affects biological systems and it depends, along with the other factors, on the time and place of exposure and population involved. In most cases, the risk appears to be higher outdoors than indoors. The indoor absorbed dose rate (nGy/h), the annual effective dose (mSv/y), Excessive lifetime cancer risks, the radium equivalent activity, the external hazard and alpha indices, the radioactivity level index were calculated for soil samples and the results are as indicated in Table 3 and Table 4 below.

3.3.1. Absorbed rate in air (DR), Annual effective dose equivalent (AEDE) and Excessive lifetime cancer risks (ELCR)

The gamma dose rate in the air at 1 meter as well as the annual effective dose equivalent from outdoor terrestrial gamma radiation for hazard estimation in soil samples were estimated using the Equations. 2, 3, 4 and 5, respectively. As shown in Table 3, the absorbed dose in air (DR) is in the range of 46.60 nGy/h to106.52 nGy/h in Bahi district and from 25.36 nGy/h to 385.97 nGy/h in Manyoni district. This indicates that the world average value (55.00 nGy/h) was exceeded as well as the world range (18.00 – 93.00) nGy/h [12], and hence the area is not safe as the absorbed dose rates are significant to cause health problems to the residents.

The annual outdoor effective dose equivalent in the present study varies from 0.06 µSv/y to 0.13 µSv/y and from 0.03 µSv/y to 0.47 µSv/y in Bahi and Manyoni, respectively. Whilst the annual indoor effective dose equivalent varies from 0.23 µSv/y to 0.52 µSv/y and from 0.12 µSv/y to 1.89 µSv/y in Bahi and Manyoni, respectively. The outdoor and indoor effective doses equivalent in the present studies are comparably less than the recommended values of 0.08 mSv/y and 0.42 mSv/y [12]. Hence the annual effective doses (outdoor and indoor) are insignificant to cause health problems to the residents.

The reported outdoor values of ELCR from this study ranged from 0.21×10^{-6} to 0.47×10^{-6} and from 0.11×10^{-6} to 1.70×10^{-6} in Bahi and Manyoni, respectively. Whilst the indoor average values of ELCR varies from 0.82×10^{-6} to 1.88×10^{-6} and from 0.45×10^{-6} to 6.82×10^{-6} in Bahi and

Manyoni, respectively [Table 3]. The safe range of *ELCR* is 0.70×10^{-3} to 1.33×10^{-3} with an average of 0.95×10^{-3} [16, 17]. According to these results, the risk of cancer is negligible.

Table 3: Estimation of Radiation Doses and Cancer Risks in from Soil samples

Area/Location		**DR** (nGy/h)	**AEDE** (μSv/y)		**ELCR (x 10^{-6})**	
			D_{out}	**D_{in}**	**For (D_{out})**	**For (D_{in})**
Bahi	Ilindi	106.52	0.13	0.52	0.47	1.88
	Chenene	46.60	0.06	0.23	0.21	0.82
	Nala	101.32	0.12	0.50	0.45	1.79
Manyoni	Rarata	59.05	0.07	0.29	0.26	1.04
	Mbaramaji	28.37	0.04	0.14	0.13	0.50
	Kitopeni	25.36	0.03	0.12	0.11	0.45
	Membeta	385.97	0.47	1.89	1.70	6.82
	Membeta	282.13	0.35	1.38	1.25	4.98

3.3.2 The Radium equivalent activity (Ra_{eq}), External hazard index (H_{ex}) and Alpha index (I_{α}) and Radioactivity Index (I_{γ})

The Radium equivalent activity represent the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K by a single quantity taking into account the radiation hazards associated with them. The values of Raeq for the soil samples are given in Table 4. The radium equivalent activity (Raeq) of soil samples from Bahi range from 99.59 Bq/kg to 237.16 Bq/kg, whilst that of Manyoni ranged from 57.09 Bq/kg to 882.08 Bq/kg. Except values of Raeq in soils samples from Membeta (Manyoni), the other Raeq values of samples are below the internationally accepted value, as mentioned earlier, the samples from Membeta had Raeq which exceed the worldwide mean value [12]. Therefore, any radium equivalent activity concentration that exceeds 370 Bq/kg may pose radiation hazards [23].

As shown in Table 4, the calculated results of external hazard index (H_{ex}) for the soil samples from Bahi range from 0.27 to 0.64 and that of Manyoni ranged from 0.15 to 2.38. Except that values from Membeta (Manyoni) which are 1.74 and 2.38, the other values are far below the criterion limit ($H_{ex} \leq 1$) as per the European Commission on Radiation Protection reports [23], and the terrestrial soil around Bahi is not contributing to higher exposure for the inhabitants and can be used as a

construction material without posing any significant radiological threat to the population. However, soils from Membeta (Manyoni) should not be used as construction material as the H_{ex} is greater than a unit. This also confirming that the upper limit of radium equivalent activity exceeded 370 Bq/kg.

Table 4: Estimated Radium equivalent and Radiation Hazards indices

Area/Location		**Raeq** (Bq/kg)	**Hex**	**Iα**	**Iγ**(Bq/kg)
Bahi	Ilindi	237.16	0.64	0.17	1.74
	Chenene	99.59	0.27	0.05	0.76
	Nala	222.29	0.60	0.15	1.65
Manyoni	Rarata	137.16	0.37	0.32	0.94
	Mbaramaji	64.89	0.17	0.12	0.46
	Kitopeni	57.09	0.15	0.16	0.40
	Membeta	882.30	2.38	4.18	5.92
	Membeta	644.08	1.74	2.90	4.34

The calculated values of alpha index (I_α) in the present study ranged from 0.05 to 0.17 in Bahi soils and from 0.12 to 4.18 in Manyoni soils. The soil samples from Membeta in Manyoni had the index values higher that the recommended limit. The recommended exemption and recommended upper levels of ^{226}Ra concentrations in building materials (like soil) are 100 Bq/kg and 200 Bq/kg [18]. When the ^{226}Ra activity concentration of building materials exceeds the value of 200 Bq/kg, it is possible that radon exhalation from this material may cause indoor radon concentration greater than 200 Bq/m^3 and those materials should be avoided. On the other hand, if ^{226}Ra concentration is less than 100 Bq/kg, than resulting indoor radon concentration would be less than 200 Bq/m^3 [20]. Therefore, the soils from Manyoni (Membeta) should be avoided and not used as building material because they might expose the population to radiation.

The estimated values of radioactivity level index (**Iγ**) ranged from 0.76 and 1.74 in soils from Bahi and 0.40 to 5.92 in soils from Manyoni. As shown in Table 4, soil samples from Ilindi and Nala from Bahi and Membeta from Manyoni had higher radioactivity level index (**Iγ**) than the international recommended value (**Iγ** $\leq$ 1), while the remaining sites (Rarata and Chenene) had the values

close to the upper limit. According to the dose criterion, the material with $\mathbf{I\gamma} \geq 1$ should be avoided, since this value corresponds to dose rate higher than 1 mSv/y [18].

4. CONCLUSION

The radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in 16 soils samples from Bahi and Manyoni were compared to that from other areas in Tanzania. Moreover, the radioactivity results were compared with that of different countries of the world. The observed difference in activity might be influenced by geological structure of the underlying rocks. The associated radiological indices from natural radionuclides were calculated and compared with the recommended limits. In some areas, the indices were higher due to eleveted of ^{226}Ra and ^{232}Th. Whilst in some areas the indices were far below the recommended limits. However, this does not guarantee the safety as the probability of occurrence of the health effects from radiation is significant. Therefore, the study recommends that the soils from Membeta should not be used as building material because they might expose the population to higher radiation levels. Further studies on the radioactivity in food crops and vegetables grown in the area are proposed. Also studies on radon and radon progeny exposure in drinking water are also suggested for the realistic quantification of the overall exposure of the public in Manyoni and Bahi districts for remedial measures and for future radiation safety.

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