__Original Research Article__

Assessment of the natural radioactivity levels in soils and the associated health risks to the public in Mbeya City

ABSTRACT

The objective of this study was to assess the natural radioactivity levels in soils from Mbeya City and their associated health risks. Thirty seven (37) soil samples were collected from ten (10) selected locations in Mbeya City. The samples were prepared and analyzed by using gamma spectrometry technique to determine the radionuclide concentrations of ^{232}Th, ^{226}Ra and ^{40}K. The obtained concentrations were used to compute for the radium equivalent, gamma dose rate, annual effective dose, external and internal hazards indices. The activity concentrations ranged from 13.98±1.99 to 275.93±25.88 Bq/kg for ^{232}Th, 5.69±1.48 to 107.49±10.61 Bq/kg for ^{226}Ra and 195.76±21.17 to 1,710.00±161.32 Bq/kg for ^{40}K with the average of 169.55 Bq/kg, 71.86 Bq/kg and 998.42 Bq/kg, respectively. The radium equivalent ranged from 41.10 to 583.93 Bq/kq with the average of 391.19 Bq/kg. The gamma dose rate ranged from 42.97 to 691.85 nGyhr^{-1} with the average of 467.57 nGyhr^{-1}. The indoor effective dose ranged from 0.21 to 3.39 mSv/y, with the average of 2.29 mSv/y while the outdoor effective dose ranged from 0.05 to 0.85 mSv/y, with the average of 0.57 mSv/y. The internal hazard index ranged from 0.13 to 1.84 Bq/kg with the average of 1.25 Bq/kg while the external hazard index ranged from 0.11 to 1.58 Bq/kg with the average of 1.06.Bq/kg. The results of this study shows the higher values than that of the world average values (for the concentrations) and also the radiation hazards indices are higher than the recommended values by the ICRP and UNSCEAR. Control measures were recommended to avoid human activities which may increase the exposure to the population. Also, selection of building materials from the areas with least levels of radioactivity and enough ventilation of houses is recommended.

• INTRODUCTION

Rocks and soils contains natural radionuclides of Uranium series (^{238}U), Thorium series (^{232}Th) and Potassium (^{40}K) in variable activity concentrations [1].The gamma radiation dose rate emitted by these primordial radionuclides of ^{238}U series, ^{232}Th series and ^{40}K is an important contribution to the average dose rate to the global population [2]. This natural radiation that originates predominantly from the upper 30 cm of the soil is a source of outdoors exposure to human beings [3]. These naturally occurring radionuclides in soils and rocks and building materials made from them, upon decay they produce external radiation exposure to all human being [4]. It is worth knowing the radioactivity levels so as to be able to set the standard and guidelines which meet the international recommendations [5]. Mbeya Region is characterized by complex geomorphology vegetation and volcanic type of soils which support the high population densities in the region for food and other sources of income. However, there is no much information available regarding the natural radioactivity levels in the region [6].

A pilot study of ambient radiation dose rates done by Tanzania Atomic Energy Commission (TAEC) in some areas of Mbeya City indicated a relatively high dose rate of background radiation. The elevated ambient radiation dose rates in the environment particularly in public occupied areas in Mbeya City can lead to annual effective dose which is above the recommended limits of 1mSv as per ICRP standards and therefore may pose health risks to humans. This created the need for a study which is the current study with the objective to assess the levels of natural radioactivity in soils and rocks and to evaluate the associated radiological health risks to the inhabitants so that measures can be taken to protect the population.

• MATERIALS AND METHODS

• The Study Area

Mbeya Region is located between latitudes 7 degrees and 9 degrees 31' south of the equator and between longitudes 32 degrees and 35 degrees east of Greenwich in Tanzania's Southern Highlands Zone. The study was conducted in Mbeya City in different locations as described in Table 1. The area was divided into eight (8) sub-blocks for sample collection. The selection of the sampling area was based on the following criteria:

- Elevated background dose rate levels according to the available source of information.
- Geological soil formation of the area
- Occupancy population density of the area
- Areas with public institutions

Table1. Sampling location coordinates with the maximum dose rates

Location	Coordinates	Mean Value dose rate (uSv/h)
Mbeya Zonal Referral Hospital	36L, 0548968, UTM 9014786	0.17
Meta Hospital	36L, 0547459, UTM 9015392	0.40
Iduda Secondary School	36L, 05611252 UTM 9012374	0.38
Majengo Primary School	36L, 0547402, UTM 9017424	0.20
Iganzo	36L, 0550993. UTM 9019169	0.13
Iyunga	36L, 0545693, UTM 9013776	0.37
Iwambi	36L, 0543119, UTM 9012059	0.28
Pandahill	36L, 0527169, UTM 9009663	0.73
Chimala Mission Hospital	36L, 0613505, UTM 9020464	0.11
Igurusi	36L, 0593433, UTM 9025646	0.08

2.2 Sample Collection and Preparation

Thirty seven (37) soil samples of 2 kg each from each sampling points were collected, parked in plastic bags and transported for laboratory measurement. The samples were then oven dried at around 105^o C for about 24hr. Then they were grinded and sieved to obtain homogeneity samples. The homogenized samples were weighed and parked in air tight steel canister containers and then stored for at least 21 days to allow circular equilibrium to take place between ^{226}Ra, ^{232}Th and their progenies.

2.3 Calibration and Sample Measurement

The gamma spectrometry technique was used for measurement and analysis. This was performed by using a Hyper-pure Germanium (HPGe) coaxial detector system model number GEM40-83-SMP and serial number 57P51572A coupled with Gammavision software for data acquisition and analysis. Energy and efficiency calibration was performed by using multi-nuclide standard source comprising of ^{241}Am, ^{139}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr, and ^{51}Cr.

2.4 Calculation of Activity Concentration

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were calculated using the following equation [7]:

(1)

Where:

) =Net peak area of the radionuclide of interest at energy E

= Efficiency of the detector for the -energy E of interest

= Intensity per decay for the-energy of interest

= Mass of the sample

=Total counting time in seconds

2.5 Determination of Radium Equivalent

The radium equivalent activity provides a single index which represents the yield from the mixture of ^{226}Ra, ^{232}Th and ^{40}K. This index is mathematically expressed as in equation 2.

(2)

where C_{Ra}, C_{Th} and C_K are the concentration activity of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.6 Indoor Gamma Dose Rate

The absorbed gamma dose rate in air at 1 m above the ground surface for uniform distribution of natural radionuclides is calculated according to UNSCEAR 2000

(3)

where C_{Ra}, C_{Th} and C_K are the concentration activity of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.7 Annual Effective Dose

The conversion factor of 0.7Sv/Gy is used to estimate the annual effective dose received by the population as a results of the radioactivity present in soil. Since adult spend about 80% of the time indoor and 20% outdoor, the indoor and outdoor occupancy factors were given as 0.8 and 0.2, respectively, according to USCEAR 2000 [4].

$$D_{in}\,(mSvy^{-1}) = D\,(nGy.h^{-1}) \times 8760h \times 0.8 \times 0.7\,(Sv.Gy^{-1}) \times 10^{-6} \qquad (4)$$

$$D_{out}\,(mSvy^{-1}) = D\,(nGy.h^{-1}) \times 8760h \times 0.2 \times 0.7\,(Sv.Gy^{-1}) \times 10^{-6} \qquad (5)$$

Where D_{in} and D_{out} are annual effective doses for indoor and outdoor environments respectively and D is the absorbed dose rate.

- **Radiation Hazard Indices**

2.8.1 Internal Hazards Index

The internal hazard index is used to evaluate the radiation levels that the sensitive organs of the body receive as the result of either ingesting or inhaling the short-lived radionuclides (radon and its decay products) [9]. It is calculated by using the following formula:

= (6)

Where, and, are the corresponding concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.8.2 External Hazard Index

The external hazards index is used to evaluate the external radiation an individual receive from an interaction with his/her physical environment. It takes into account all forms of gamma radiation emitted by primordial radionuclides present in soils, rocks and plants to determine indoor radiation dose received by an individual. The index is calculated by using equation 7 [10]

= (7)

Where, and, are the corresponding concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

3. RESULTS AND DISCUSSION

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K from the measurements performed in the laboratory for the thirty seven (37) samples using gamma spectrometry are presented in Table 2. This table indicates the specific activity at each sampling location.

Table2. Specific activity of ^{232}Th, ^{226}Ra and ^{40}K in soil from selected sites of Mbeya City

Sample ID	Location	Activity Concentration (Bq/kg)		
		^{232}Th	^{226}Ra	^{40}K
CH1	Chimala	251.42±23.26	96.40±9.13	1,083.10±99.38
CH3	Chimala	76.91±8.09	22.77±2.58	1,710.00±161.32
ID1	Iduda	167.07±17.42	99.04±9.73	1,241.50±116.00
ID2	Iduda	257.55±24.89	107.49±10.61	1,254.00±119.79
ID3	Kiwila	275.93±25.88	94.73±9.34	1,228.80±114.75
IG1	Igurusi	94.55±8.69	37.44±3.80	873.86±80.26
IG2	Igurusi	117.47±11.42	62.24±6.73	971.56±98.22
IG3	Igurusi	95.05±9.52	37.59±4.10	781.70±73.32
IG4	Igurusi	173.27±15.82	75.77±7.22	858.83±79.33
IGA1	Iganzo	13.98±1.99	6.04±1.05	195.76±21.17
IGA2	Iganzo	62.05±5.95	33.88±3.23	531.40±49.82
IGA3	Iganzo	15.06±1.75	5.69±1.48	197.28±23.15
IGA3	Iganzo	136.93±13.20	57.49±5.65	1,286.00±121.05
IW1	Iwambi	157.62±14.54	85.91±8.44	1,090.00±101.80
IW2	Iwambi	242.24±23.03	95.02±9.07	1,088.80±102.75
IW3	Iwambi	213.06±21.01	78.37±7.91	932.60±88.15
IW4	Iwambi	225.32±20.62	89.03±8.73	949.43±88.80
IW5	Iwambi	227.78±20.84	96.71±9.29	1,061.60±98.98
IY1	Iyunga Tech. School	201.92±18.76	77.25±7.41	926.53±85.39
IY2	Iyunga Tech.School	241.16±22.38	92.37±8.63	1,075.60±98.33
IY3	Iyunga Tech. School	274.65±25.55	97.99±9.42	1,050.20±97.75
IY5	Iyunga Tech. School	169.17±16.34	99.33±9.29	1,112.40±101.84
MJ1	Majengo P/School	210.65±19.28	83.37±8.05	1,143.00±106.03
MJ4	Majengo P/School	174.01±16.76	73.77±7.03	1,111.10±103.34
MJ5	Majengo P/School	187.01±17.36	76.53±7.22	1,100.50±100.56
MR1	Mbeya Referral Hosp	89.73±8.32	36.37±3.89	768.65±71.59
MR2	Mbeya Referral Hosp	178.73±17.24	61.67±5.81	1,102.20±102.31
MR3	Mbeya Referral Hosp	257.53±23.59	102.66±9.95	1,129.80±105.97
MR4	Mbeya Referral Hosp	217.23±20.81	91.91±8.76	1,141.80±107.82
MS2	Meta Hospital	164.42±15.11	87.93±8.53	1,051.40±97.82
MT1	Meta Hospital	158.17±14.61	87.74±8.00	1,106.90±99.74

MT2	Meta Hospital	181.54±16.72	76.99±7.38	1,028.50±96.71
PS1	Pandahill Secondary	197.77±18.51	60.92±5.79	891.73±82.76
PS2	Pandahill Secondary	197.10±17.97	87.28±8.27	1,011.80±92.83
PS3	Pandahill Secondary	77.88±7.29	36.71±3.58	733.25±69.07
PS4	Pandahill Secondary	196.00±17.96	72.66±7.12	999.37±92.95
PS5	Pandahill Secondary	95.30±10.66	73.85±7.17	1,120.80±104.25

The concentration of ^{232}Th in the samples ranged from 13.98±1.99 to 275.93±25.88 Bq/kg with the average concentration of 169.55 Bq/kg while the concentrations of ^{226}Ra and ^{40}K in the samples ranged from 5.69±1.48 to 107.49±10.61 Bq/kg and 195.76±21.17 to 1,710.00±161.32 Bq/kg, with the average concentrations of 71.86 Bq/kg and 998.42 Bq/kg respectively. These data indicated that the studied areas at Mbeya City areas has elevated levels of natural radioactivity in the soil which are above the world average of 45 Bq/kg, 33 Bq/kg and 420 Bq/kg for ^{232}Th, ^{226}Ra and ^{40}K, respectively as indicated in Table 2. The elevated levels of natural radioactivity in soil can be explained by the geological soil characteristics of Mbeya region, which is characterized by the volcanic type of soil [6]. The volcanic soil is said to be associated with rich amount of radioactivity [11]. The radium equivalent ranged from 41.10 to 583.93 Bq/kq with the average of 391.19 Bq/kg, presented in Table 4. This obtained average value of radium equivalent is above the world limit of 370 Bq/kg, according to UNSCEAR 2000 [4]. From these data, 70% of the sampled locations indicated the higher values of radium equivalent above the limit. The Gamma dose rate ranged from 42.97 to 691.85 nGyhr^{-1} with the average of 467.57 nGyhr^{-1}. This amount of gamma dose rate exceeds the world average which is 60 nGyhr^{-1} according to UNSCEAR 2000 [4].

Table 3. Comparison of average concentration in soil for this study with the world average

Radionuclide	This Study (Bq/kg)	World Average (Bq/kg)
^{232}Th	169.55	45 [4]
^{226}Ra	71.86	33 [4]
^{40}K	998.42	420 [4]

Using the indoor occupancy factor of 0.8 and outdoor occupancy factor of 0.2, the indoor and outdoor effective doses were computed and the results are presented in Figure 1 and Table 3. The indoor effective dose ranged from 0.21 to 3.39 mSv/y, with the average of 2.29 mSv/y while the outdoor effective dose ranged from 0.05 to 0.85 mSv/y, with the average of 0.57 mSv/y. The maximum indoor and outdoor effective doses were observed at Iduda Secondary School area while the minimum values were found at Iganzo.

These calculated values of the annual effective dose are higher than the reported values by UNSCEAR 2000 [4]. According to UNSCEAR, the world average indoor annual effective is 0.41 mSv while the average outdoor annual effective dose is 0.07 mSv. The higher calculated values of the effective dose is due to the elevated levels of background radiation observed in this studied area, i.e. the higher concentrations of the ^{232}Th, ^{226}Ra and ^{40}K from the laboratory analysis results (Table 2).

Figure1. Calculated indoor and outdoor effective doses against UNSCEAR 2000 values

The internal and external hazard indices were computed using equation 6 and the results are shown in Table 3. The internal hazard index ranged from 0.13 to 1.84 Bq/kg with the average of 1.25 Bq/kg while the external hazard index ranged from 0.11 to 1.58 Bq/kg with the average of 1.06.Bq/kg. The maximum internal and external hazard indices together with their average values calculated in this study were above the limit of 1 Bq/kg recommended by the European Commission [12]. The maximum values of external and internal hazard indices were observed at Iduda Secondary School area while the minimum internal and external indices were observed at Iganzo area as shown in Figure 2. Moreover, except at Igurusi and Iganzo areas, the remaining studied areas showed higher values of the external and internal hazards indices compared to the recommended one.

Table 4. Radiation hazard index at each sampling location

Location	Radium Equivalent (Bq/kg)	Gamma Dose Rate (nGy/hr)	Indoor Effective Dose (mSv/y)	Outdoor Effective Dose (mSv/y)	Internal Hazard Index (H_{in}) (Bq/kg)	External Hazard Index (H_{ex}) (Bq/kg)
Chimala	539.33	631.43	3.10	0.77	1.72	1.46
Chimala	264.42	220.67	1.08	0.27	0.78	0.71
Iduda	433.55	597.44	2.93	0.73	1.44	1.17
Iduda	572.34	691.85	3.39	0.85	1.84	1.55
Kiwila	583.93	645.28	3.17	0.79	1.83	1.58
Igurusi	239.93	262.21	1.29	0.32	0.75	0.65
Igurusi	305.03	391.18	1.92	0.48	0.99	0.82
Igurusi	233.70	259.35	1.27	0.32	0.73	0.63
Igurusi	389.68	481.50	2.36	0.59	1.26	1.05

Iganzo	41.10	43.80	0.21	0.05	0.13	0.11
Iganzo	163.53	211.86	1.04	0.26	0.53	0.44
Iganzo	42.42	42.97	0.21	0.05	0.13	0.11
Iganzo	352.32	395.18	1.94	0.48	1.11	0.95
Iwambi	395.24	526.67	2.58	0.65	1.30	1.07
Iwambi	525.26	619.81	3.04	0.76	1.68	1.42
Iwambi	454.86	520.89	2.56	0.64	1.44	1.23
Iwambi	484.34	576.77	2.83	0.71	1.55	1.31
Iwambi	504.18	617.24	3.03	0.76	1.62	1.36
Iyunga Tech. School	437.34	508.72	2.50	0.62	1.39	1.18
Iyunga Tech. School	520.05	606.77	2.98	0.74	1.65	1.40
Iyunga Tech. School	571.60	651.58	3.20	0.80	1.81	1.54
Iyunga Tech. School	426.90	594.65	2.92	0.73	1.42	1.15
Majengo P/School	472.61	550.47	2.70	0.68	1.50	1.28
Majengo P/School	408.16	483.55	2.37	0.59	1.30	1.10
Majengo P/School	428.69	503.50	2.47	0.62	1.36	1.16
Mbeya Referral Hospital	223.87	250.06	1.23	0.31	0.70	0.60
Mbeya Referral Hospital	402.12	432.12	2.12	0.53	1.25	1.09
Mbeya Referral Hospital	557.92	665.11	3.26	0.82	1.78	1.51
Mbeya Referral Hospital	490.47	592.62	2.91	0.73	1.57	1.32
Meta Hospital	404.01	538.29	2.64	0.66	1.33	1.09
Meta Hospital	399.15	535.88	2.63	0.66	1.32	1.08
Meta Hospital	415.79	499.15	2.45	0.61	1.33	1.12
Pandahill Secondary	412.39	431.83	2.12	0.53	1.28	1.11
Pandahill Secondary	447.04	554.03	2.72	0.68	1.44	1.21
Pandahill Secondary	204.54	242.74	1.19	0.30	0.65	0.55
Pandahill Secondary	429.89	487.60	2.39	0.60	1.36	1.16
Pandahill Secondary	296.43	435.44	2.14	0.53	1.00	0.80

Table 5. Comparison between radiation hazard indices from soils obtained in some world region and this study

Location	Radium Equivalent (Bq/kg)	Gamma Dose Rate (nGy/hr)	Indoor Effective Dose (mSv/y)	Outdoor Effective Dose (mSv/y)	Internal Hazard Index (H_{in}) (Bq/kg)	External Hazard Index (H_{ex}) (Bq/kg)	Reference
Papinat,India	82.24 –	32.01 –	0.09 –	0.039 –	0.207 -	0.234 -	[13]
Oban Massif,	108.49	56.47	0.158	0.069	0.286	0.339	[10]
Nigeria	92.52 –	83.04 –	0.41 –	0.1 – 1.24	0.31 -	0.20 -	[9]
Pengerang	1246.38	1012.24	4.97	0.07– 0.5	4.09	3.37	[14]
Johor,	13.95 –	5.72 –	–	–	0.05 -	0.03 -	[15]
Malaysia	81.05	36.91	–	0.1067	0.29	0.22	[16]
Bukit Kledang,	44.70 –	19.46 –	–	0.35 –	-	0.12 -	[17]
Malaysia	89.89	39.69	–	1.90	0.287	0.24	[18]
East Coast of	102.56	86.95	–	0.01 –	0.23 –	0.277	[19]
Tamilnadu,	21.19 –	46.78 –	–	0.13	1.22	0.08-	This study
India	145.28	247.91	–	0.0286 -	0.11 -	0.45	
Kalimantan,	–	14.18 –	0.21 –	1.69	0.73	0.08 -	
Indonesia	–	105.99	3.39	0.02 – 0.9	–	0.61	
Laos, Vietnam	14.6 –	23.32 –		0.05 –	0.05 –	–-	
Homa Bay	859.1	1369.91		0.85	2.9	0.04 –	
County, Kenya	41.10 –	7.0 –			0.13 –	2.3	
Northern	583.93	385.1			1.84	0.11 –	
Uganda		42.97 –				1.58	

Mbeya, Tanzania		691.85					

Figure 2: Calculated average radiation hazard indices at each site

Further, the correlation analysis was performed to compare the dose rates measurements at the sampled locations to the calculated results of soil radioactivity respectively. The results of this analysis are presented in Figure 3. The results show a moderate positive correlation with the correlation coefficient of 0.4. This moderate positive correlation shows that the dose rates measured at the locations were the results of the radionuclides concentration levels present in the soil.

Fig. 3. Correlation between measured and calculated dose rates

4. CONCLUSION

The natural radioactivity levels of ^{232}Th, ^{226}Ra and ^{40}K has been determined in soil from Mbeya City and their associated health risk. The results in this study area showed elevated levels of natural radioactivity. The mean concentration of ^{232}Th, ^{226}Ra and ^{40}K were 169.55 Bq/kg, 71.86 Bq/kg and 998.42 Bq/kg, respectively. These values are higher than the world average and it is attributed to the geological type of soil formation in Mbeya City which is a volcanic type of soil. The calculated dose rates, the annual effective dose and the radiation hazard indices were higher than values recommended by ICRP and UNSCEAR. This implies that the population living in Mbeya City is subjected to health risks caused by the radiation exposure emanating from the radionuclides existing in the soil.

Therefore, control measures are recommended to those areas with elevated radiation doses to avoid human activities which may contribute to increase the effective dose to the population. The planting trees in those areas are highly recommended to conserve the soil. The City council management is recommended to use the data to make a careful selection of sites for building materials from the areas with least levels of radioactivity. Moreover, the awareness programs should be conducted to encourage the public to build houses with enough ventilation to avoid accumulation of radon gas originated from radium.

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