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Assessment of the Natural Radioactivity Levels in Soils and the Associated Health Risks to the Public in Mbeya City, Tanzania

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Authors' contributions

This work was carried out in collaboration among all authors. Author MR designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors YS and SN managed the analyses of the study. Authors HM and AM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this study was to assess the radioactivity levels in soils from Mbeya City and their associated health risks. Samples were collected from selected locations. Then, the samples were analyzed by using an HPGe detector to determine the concentrations of ^{232}Th, ^{226}Ra, and ^{40}K. The concentrations were used to compute the radiation indices. The 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 an 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/kg with an average of 391.19 Bq/kg. The gamma dose rate ranged from 42.97 to 691.85 nGyhr^{-1} with an

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average of 467.57 nGyhr^{-1}. The indoor effective dose ranged from 0.21 to 3.39 mSv/y, with an average of 2.29 mSv/y while the outdoor effective dose ranged from 0.05 to 0.85 mSv/y, with an average of 0.57 mSv/y. The internal hazard index ranged from 0.13 to 1.84 Bq/kg with an average of 1.25 Bq/kg while the external hazard index ranged from 0.11 to 1.58 Bq/kg with an average of 1.06.Bq/kg. The results indicate elevated levels of background radiation above the world average and the hazard indices above the ICRP and UNSCEAR recommendations. Therefore, control measures were recommended to protect the public against possible health risks.

Keywords: Natural radioactivity; radiation hazards; radium equivalent; effective dose.

1. INTRODUCTION

Rocks and soils contain 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 of the global population [2]. This natural radiation that originates predominantly from the upper 30 cm of the soil is a source of outdoor exposure to human beings [3]. These naturally occurring radionuclides in soils and rocks and building materials made from them, upon decay, produce external radiation exposure to all human beings [4]. It is worth knowing the radioactivity levels to be able to set the standard and guidelines that 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 not much information available regarding the natural radioactivity levels in the region [6].

A pilot study conducted in selected areas of Mbeya City by the Tanzania Atomic Energy Commission (TAEC), the government body responsible for regulating all the atomic energy matters in the country indicated a relatively high dose rate of background radiation. This can lead to an annual effective dose above the recommended levels which may pose health risks to humans. This created the need for the current study. The objective of this study is to assess levels of natural radioactivity in soils and rocks and the associated radiological health risks to the inhabitants.

2. MATERIALS AND METHODS

2.1 The Study Area

Mbeya Region is located in southwest Tanzania with the GPS coordinates 36L 0550658.46, UTM 9015132.62. It is situated at an altitude of 1,700 metres and surrounded by high mountains. Mbeya City is the capital of the surrounding rural Mbeya region. The city has an urban population of 649,000 in 2023.

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:

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

Table 1. The 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 Measurement of Ambient Dose Rates

The dose rates at the sampling points were measured at a distance of one (1) meter above the ground by using the Rotem Radiation Survey Meter, Model No. RAM DAM 2000. To record a reading, ten readings were collected and then averaged to get a representative value of the dose rate at a sampling point.

2.3 Sample Collection and Preparation

Thirty-seven (37) soil samples of 2 kg each from each sampling point were collected, parked in plastic bags, and transported for laboratory measurement. The samples were then oven-dried at around 105º C for about 24 hours. 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 secular equilibrium to take place between ^{226}Ra, ^{232}Th, and their progenies.

2.4 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 a multi-nuclide standard source comprising ^{241}Am, ^{139}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr, and ^{51}Cr.

2.5 Calculation of Activity Concentration

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

$$A = \frac{N(E_\gamma)}{\varepsilon(E_\gamma) I_\gamma M T_c} \quad (1)$$

Where:

$N(E_\gamma)$ =Net peak area of the radionuclide of interest at energy E

$\varepsilon(E_\gamma)$ = Efficiency of the detector for the γ-energy E of interest

I_γ = Intensity per decay for the γ-energy of interest

M = Mass of the sample

T_c =Total counting time in seconds

2.6 Determination of Radium Equivalent

The radium equivalent activity provides a single index that represents the yield from the mixture of ^{226}Ra, ^{232}Th, and ^{40}K. This index is mathematically expressed as in Equation 2 [8].

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

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

2.7 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

$$D(nGyh^{-1}) = 4.462C_{Ra} + 0.621C_{Th} + 0.0417C_K$$
[9] (3)

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

2.8 Annual Effective Dose

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

$$Din\ (mSvy-1) = D\ (nGy.h-1) \times 8760h \times 0.8 \times 0.7\ (Sv.Gy-1) \times 10-6 \quad (4)$$

$$Dout\ (mSvy-1) = D\ (nGy.h-1) \times 8760h \times 0.2 \times 0.7\ (Sv.Gy-1) \times 10-6 \quad (5)$$

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

2.9 Radiation Hazard Indices

2.9.1 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 short-lived radionuclides (radon and its decay products) [10]. It is calculated by using Equation (6) [11]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

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

2.9.2 External hazard index

The external hazards index is used to evaluate the external radiation an individual receives 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 the indoor radiation dose received by an individual. The index is calculated by using Equation 7 [12].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

Where A_{Ra}, A_{Th} and, A_K 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.

The concentration of ^{232}Th in the samples ranged from 13.98±1.99 to 275.93±25.88 Bq/kg with an average of 169.55 Bq/kg while the concentrations of ^{226}Ra and ^{40}K 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, respectively with an average of 71.86 Bq/kg and 998.42 Bq/kg, respectively. These data indicated that the studied areas at Mbeya City have 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 the Mbeya region, which is characterized by the volcanic type of soil [6]. The volcanic soil is said to be associated with a rich amount of radioactivity [13]. The radium equivalent ranged from 41.10 to 583.93 Bq/kg with an average of 391.19 Bq/kg, presented in Table 4. This average value of radium equivalent is above the world limit of 370 Bq/kg, according to UNSCEAR 2000 [4, 14]. From these data, 70% of the sampled locations indicated higher values of radium equivalent above the limit. The Gamma dose rate ranged from 42.97 to 691.85 $nGyhr^{-1}$ with an 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].

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 Fig. 1 and Table 3. The indoor effective dose ranged from 0.21 to 3.39 mSv/y, with an average of 2.29 mSv/y while the outdoor effective dose ranged from 0.05 to 0.85 mSv/y, with an average of 0.57 mSv/y. The maximum indoor and outdoor effective doses were observed at the 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 are 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).

The internal and external hazard indices were computed using Equation 6 and the results are shown in Table 4. The internal hazard index ranged from 0.13 to 1.84 Bq/kg with an average of 1.25 Bq/kg while the external hazard index ranged from 0.11 to 1.58 Bq/kg with an 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 safe limit of 1 Bq/kg recommended by the European Commission, ICRP, and UNSCEAR [15, 16]. The maximum values of external and internal hazard indices were observed at the Iduda Secondary School area. In contrast, the minimum internal and external indices were observed at the Iganzo area as shown in Fig.2. Moreover, except for the Igurusi and Iganzo areas, the remaining studied areas showed higher values of the external and internal hazards indices compared to the recommended ones.

Further, the correlation analysis was performed to compare the dose rates measurements at the sampled locations to the calculated results of soil

Table 2. The 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

Sample ID	Location	Activity Concentration (Bq/kg)		
		^{232}Th	^{226}Ra	^{40}K
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

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]

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	3.1	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	233.7	259.35	1.27	0.32	0.73	0.63
Igurusi	389.68	481.5	2.36	0.59	1.26	1.05
Iganzo	41.1	43.8	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	1.3	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	2.5	0.62	1.39	1.18
Iyunga Tech. School	520.05	606.77	2.98	0.74	1.65	1.4
Iyunga Tech. School	571.6	651.58	3.2	0.8	1.81	1.54
Iyunga Tech. School	426.9	594.65	2.92	0.73	1.42	1.15
Majengo P/School	472.61	550.47	2.7	0.68	1.5	1.28
Majengo P/School	408.16	483.55	2.37	0.59	1.3	1.1
Majengo P/School	428.69	503.5	2.47	0.62	1.36	1.16
Mbeya Referral Hospital	223.87	250.06	1.23	0.31	0.7	0.6
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

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)**
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	0.3	0.65	0.55
Pandahill Secondary	429.89	487.6	2.39	0.6	1.36	1.16
Pandahill Secondary	296.43	435.44	2.14	0.53	1	0.8

Table 5. Comparison between radiation hazard indices from soils obtained in some world regions 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
Panipat, India	82.24 – 108.49	32.01 – 56.47	0.09 – 0.158	0.039 – 0.069	0.207 - 0.286	0.234 - 0.339	[17]
Oban Massif, Nigeria	92.52 – 1246.38	83.04 – 1012.24	0.41 – 4.97	0.1 – 1.24	0.31 - 4.09	0.20 - 3.37	[12]
Pengerang Johor, Malaysia	13.95 – 81.05	5.72 – 36.91	–	0.07– 0.5	0.05 - 0.29	0.03 - 0.22	[10]
Bukit Kledang, Malaysia	44.70 – 89.89	19.46 – 39.69	–	–	-	0.12 - 0.24	[18]
East Coast of Tamilnadu, India	102.56	86.95	–	0.1067	0.287	0.277	[19]
Kalimantan, Indonesia	21.19 –145.28	46.78 – 247.91	–	0.35 –1.90	0.23 –1.22	0.08-0.45	[20]
Laos, Vietnam	–	14.18 – 105.99	–	0.01 – 0.13	0.11 - 0.73	0.08 - 0.61	[21]
Homa Bay County, Kenya	–	23.32 –1369.91	–	0.0286 - 1.69	–	–-	[22]
Northern Uganda	14.6 – 859.1	7.0 – 385.1	–	0.02 – 0.9	0.05 – 2.9	0.04 – 2.3	[23]
Kathmandu, Nepal	82.779	36.394	–	0.045	0.253	0.224	[24]
Eastern Nepal	122.7 ± 34.0	57.7 ± 14.9	–	0.3 ± 0.1	–	–	[25]
Mbeya, Tanzania	41.10 – 583.93	42.97 – 691.85	0.21 – 3.39	0.05 – 0.85	0.13 – 1.84	0.11 – 1.58	This study

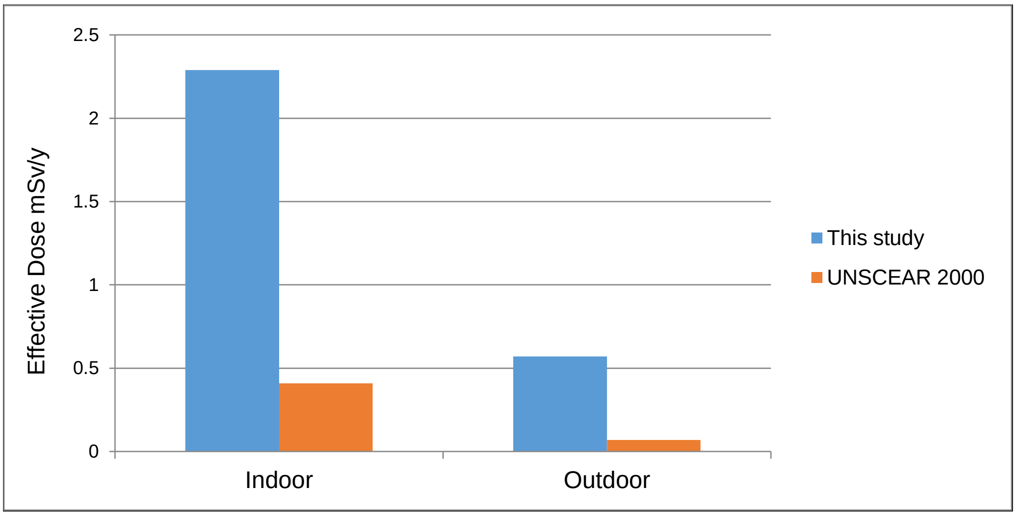

Fig. 1. Calculated indoor and outdoor effective doses against UNSCEAR 2000 values

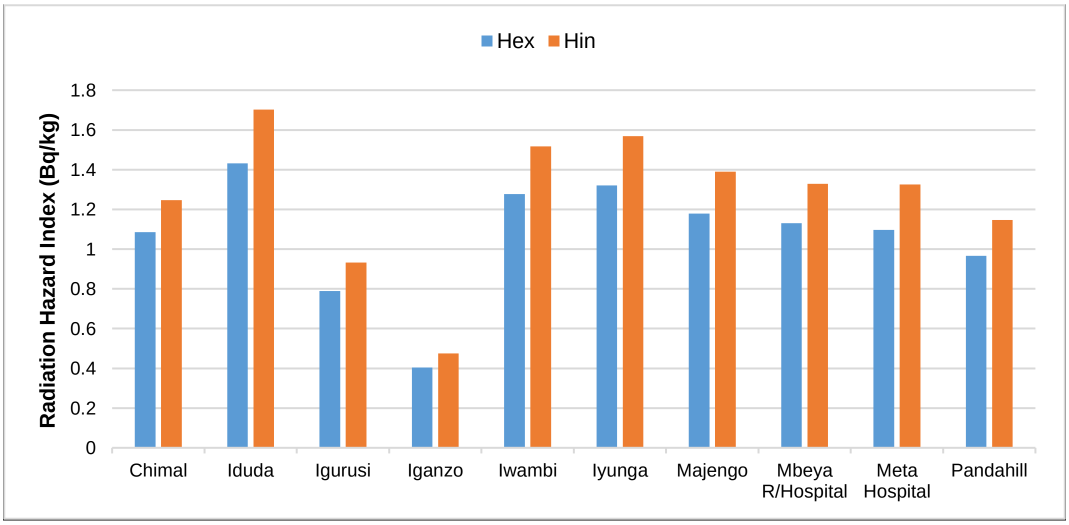

Fig. 2. Calculated average radiation hazard indices at each site

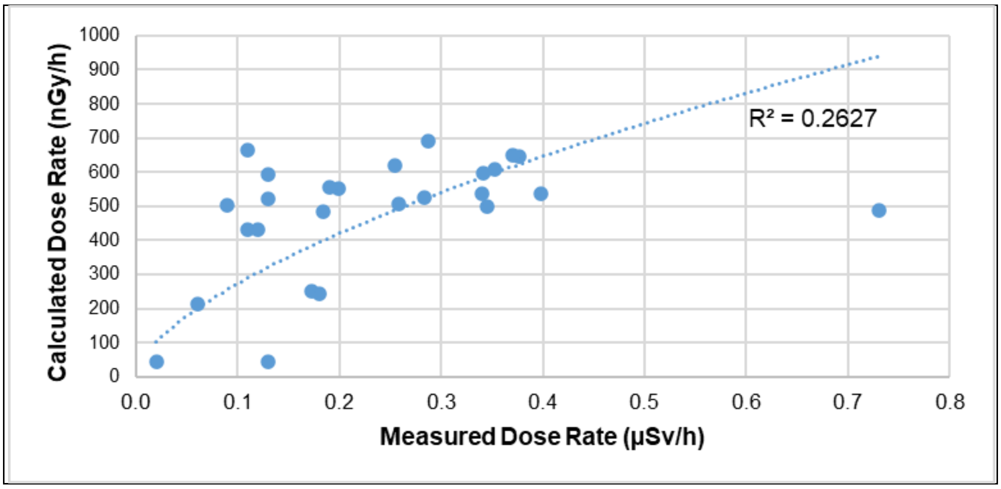

Fig. 3. Correlation between measured and calculated dose rates

radioactivity respectively. The results of this analysis are presented in Fig. 3. The results show a moderate positive correlation with a 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.

4. CONCLUSION

This study assessed the natural radioactivity levels of ^{232}Th, ^{226}Ra, and ^{40}K in soils and the associated health risks to the public in Mbeya City. The studied area was found to contain elevated levels of background radiation above the world average. Also, the calculated radiation hazard indices were above the world average. This could pose health risks to the public. Therefore, the appropriate measures are recommended to protect the public including avoiding human activities that may contribute to the increase of the effective dose to the population, careful selection of sites for building materials, and awareness programs should be conducted to encourage the public to build houses with enough ventilation to avoid the accumulation of radon.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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