Natural Radioactivity Levels in the Area around the Uranium Deposit of the Bahi District in Dodoma Region, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Author EEK designed the study and performed the analysis including the statistical analysis of the study. Author NKM supervised the analysis of the samples and wrote the manuscript. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

In this study samples of soil and water from different villages in the Bahi wetlands were analyzed for radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K using gamma ray spectrometry. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil were found to be highest in the northern zone of the study area compared to the central and southern zones. The northern zone includes the Kisalalo uranium deposit of which exploration is still going on. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from northern zone were 37.3±0.7, 51.1±0.9 and 874.9±9.0 Bqkg^{-1}, respectively. The Central Zone had the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K as 23.4±0.5, 25.8±0.5 and 495±5 Bqkg^{-1}, respectively, while that from southern zone were 25.2±0.5, 37.3±0.7 and 368±4 Bqkg^{-1}, respectively. In water samples, the activity concentrations of ^{226}Ra were below the detection limit (0.11 Bql^{-1}) for the system used in this study. The concentrations of ^{232}Th and ^{40}K were found to range from < 0.07 to 0.740±0.003 Bql^{-1} and < 1.01 to 4.36±0.05 Bql^{-1}, respectively. The average concentrations of ^{226}Ra and ^{232}Th in drinking water samples from the

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study area were found to be lower than the guidance levels of these radionuclides (1.0 Bql^{-1} for ^{226}Ra and ^{232}Th) in drinking water recommended by the WHO.

1. INTRODUCTION

Natural radioactivity is part of our natural surroundings, and human and non human beings have been exposed externally and internally due to the presence of these radionuclides. Gamma radiation emitted from naturally occurring radioisotopes, such as ^{40}K, ^{232}Th, and ^{238}U and their decay products, which exists at trace levels in all ground formations, represents the main external source of irradiation to human body [1]. However, in some areas in the world the radioactivity concentrations are high due to the presence of phosphate as well as uranium deposits [2,3]. Accordingly UNSCEAR report (1993) [4] reported that ^{226}Ra, ^{232}Th, and ^{40}K activities are elevated in the granites which are rich in uranium and thorium.

In Tanzania high background radiation areas have been reported to be that in Minjingu where there is phosphates deposit as well as in Mkuju where there are uranium deposits [2,5]. Viable uranium deposits have also been discovered in Bahi and Manyoni districts. The deposits are reported to be shallow as that of Mkuju; therefore concentration of radioactivity might also be high in the areas at the vicinity of the deposits [6,7]. The main geographic feature in the district is the Bahi wetlands which serve as a source for agricultural and other economic activities within the area. The presence of uranium deposits in Bahi has brought a serious concern as several reports in the literature indicate high activity concentrations in regions near uranium deposits. Tripathi, et al. [8] in India, Geraldo et al. [9] in Brazil as well as Enkhbat et al. [10] in Mongolia reported higher activity concentrations of ^{238}U and ^{232}Th compared to the world average as per UNSCEAR report [11]. Mohammed and Mazunga [12] reported high activity concentration of ^{238}U in Likuyu village; 54 km east of Mkuju uranium deposit. The concern goes further to uranium mining that may start soon as uranium mining if not well controlled might contaminate the environment.

This study has determined the radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from villages in the wetlands so as to assess the radioactivity levels prior to mining.

The data will also act as reference in the future when assessing contamination of the area from mining.

2. MATERIALS AND METHODS

2.1 Study Area

Bahi wetlands are about 60 km north-west of the capital Dodoma, between latitudes 05º51′ and 06º20′ South and longitudes 34º59′ and 35º21′ east. The wetlands cover an area of about 2000 km^2 with the population of about 150,000 [13]. The wetlands offer a wide range of livelihood options to communities as compared to the surrounding dry lands [14]. Several studies have highlighted the importance of the wetlands to the local communities, which include agriculture, livestock keeping, salt production and fishing [15,14]. Apart from river Bubu, Bahi wetlands receive water from various seasonal rivers, mainly draining from northern side of the Bahi wetlands. A major part of the wetlands is composed of a swamp known as the Bahi swamp and the remaining part is small scale farms as well as settlements. The swamp has an area of about 1000 km^2 and is located in the south-west of the wetlands. Major activities at the swamp are salt production as well as fishing, and the areas around the swamp are nice grazing area for cattle [16]. The climatic condition of the area is semi-arid with short rainy season extending from December to March. Mean annual rainfall across the area is approximately 600 mm with slightly higher rainfall at the higher altitudes in the northern part of the area [17]. Geology of the area comprises of biotite granites, sedimentary rocks as well as scattered exposures of the basement rocks of volcanic [39].

2.2 Sampling Methodology and Sample Preparation

A total of 25 undisturbed soil samples of about 2 kg each were randomly collected from 8 identified points using the standard sampling procedures [18]. The area was divided into three zones; northern zone (NZ) central zone (CN) and southern zone (SN) as shown in Fig. 1. The selection of sampling locations within each zone

was based on the accessibility of the station to the public, as well as their proximity to the exploration sites. The surface soils were collected at the depth level between 0-15 cm from each location [19]. The collected samples were then placed in labelled polyethylene bags and transferred to the TAEC laboratory for preparation and analysis. In the laboratory, soil samples were oven-dried at the temperature of 105° C for between 3 and 4 hours until the moisture was completely removed [20]. 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 [21,20]. 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. Also a total of ten (10) water samples were randomly collected in the study area. Out of these; 4 were collected from the surface of the Bubu River, 3 from three domestic water wells in Bahi town and Bahi Sokoni, and 3 from Bahi Swamp near the salt production area. Samples were collected and filled into 2 litres acid pre-cleaned polyethylene container to avoid wall absorption [IAEA, 1989]. The containers were labelled and transported to the TAEC laboratory for preparation and analysis. The water samples were then transferred into well sealed 500 ml marinelli beakers without any special treatment.

2.3 Gamma Ray Spectrometry

The study used a P-type coaxial high purity germanium detector (HPGe) with relative efficiency of 51.0% and resolution of 1.80 keV at 1332 keV energy of ^{60}Co. Detector chamber is shielded with three layers of copper, cadmium and lead of 30 mm, 3 mm and 100 mm thick, respectively. Energy and efficiency calibration were performed using the multi-nuclide standard packed in a 500 ml marinelli beaker. The standard (MBSS 2) contained 10 radionuclides (^{241}Am, ^{109}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr, ^{88}Y and ^{203}Hg) with production No. 130113-1395013 and reference date of 8th February 2013.

The activity of ^{226}Ra was determined using the gamma-lines of ^{214}Pb (295.2 and 351.9 keV) and ^{214}Bi (609.3 keV). The activity for ^{232}Th was measured from ^{212}Pb (238.6 keV), ^{228}Ac (338.3 and 911.1 keV) and ^{208}Tl (583.2 keV). The ^{40}K

was measured from its gamma line energy of 1460.8 keV.

Activity concentration (Bqkg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in the samples were calculated using the following analytical expression as shown in equation (1) [22].

$$A_{sp} = \frac{N_{sam}}{P_E\,\varepsilon\,(E)\,T_c\,M}$$ (1)

where,

A_{sp} is the specific activity concentration of radionuclide in the sample,
N_{sam} is the net counts of the radionuclide in the sample,
P_E is the gamma-ray emission probability,
$\varepsilon(E)$ is the absolute counting efficiency of the detector system,
T_c is the sample counting time,
M is the mass of the sample in kg or volume (l),

3. RESULTS AND DISCUSSION

3.1 Radioactivity Concentrations in Soil

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples collected from different locations in the three zones of the Bahi district and the average values of the zones are given in Tables 1.1, 1.2 and 1.3. The Northern zone (NZ) has the highest average activity concentrations of all radionuclides than Central zone (CZ) and Southern zone (SZ). The NZ includes the Bahi Township which is about 10 km from the exploration area at Kisalalo uranium deposits. The average activity concentrations of ^{226}Ra in the CZ and SZ are similar. This value is 37% lower than that of NZ.

The average values of the three radionuclides from the three zones of the Bahi wetlands are compared with those from other places in Tanzania and the world as shown in the Table 1.4. The average values of ^{226}Ra, ^{232}Th and ^{40}K were found to be 84%, 36% and 37% respectively lower than the values obtained in Mkuju uranium deposit [5]. This might be because the study at Mkuju were conducted within the uranium deposit site compared to the samples in this study which was collected in villages about 5 to 20 km from the uranium deposits. The average activity of ^{226}Ra was lower than its value reported at Likuyu village 53 km

from Mkuju uranium deposit [12]. High activity levels of [226]Ra in Likuyu were reported to be influenced by the presence of rivers Mkuju and Kilowero flowing from the Mkuju deposits to the village. The mean activity concentrations of [226]Ra, [232]Th and [40]K in NZ were found to be slightly higher than the values reported in Windhoek, Namibia about 400 km from a major uranium mine [3]. However these values were found to be 4, 3 and 2 times respectively, lower than the values reported from a high radiation background area of Lolodorf, southern part of Cameroon [23]. The mean value of [226]Ra in NZ is also about two times lower than the value reported in Ireland [24]. The mean concentrations of [226]Ra in samples from NZ was found to be higher than 15%, lower than 25% and similar to 60% of the concentrations reported

in countries compiled by UNSCEAR, 2000. The mean concentration of [232]Th obtained from NZ is higher than 75% of the countries reported in the UNSCEAR, (2000) but comparable to the world average value and lies within the range of the reported countries [25]. The concentration levels of the three radionuclides were similar to the values reported in other places in the world.

3.2 Radioactivity Concentrations in Water

The activity concentrations of [226]Ra, [232]Th and [40]K in the soil samples collected from different locations in the three zones of the Bahi district and the average values of the zones are given in Tables 1.5, 1.6 and 1.7.
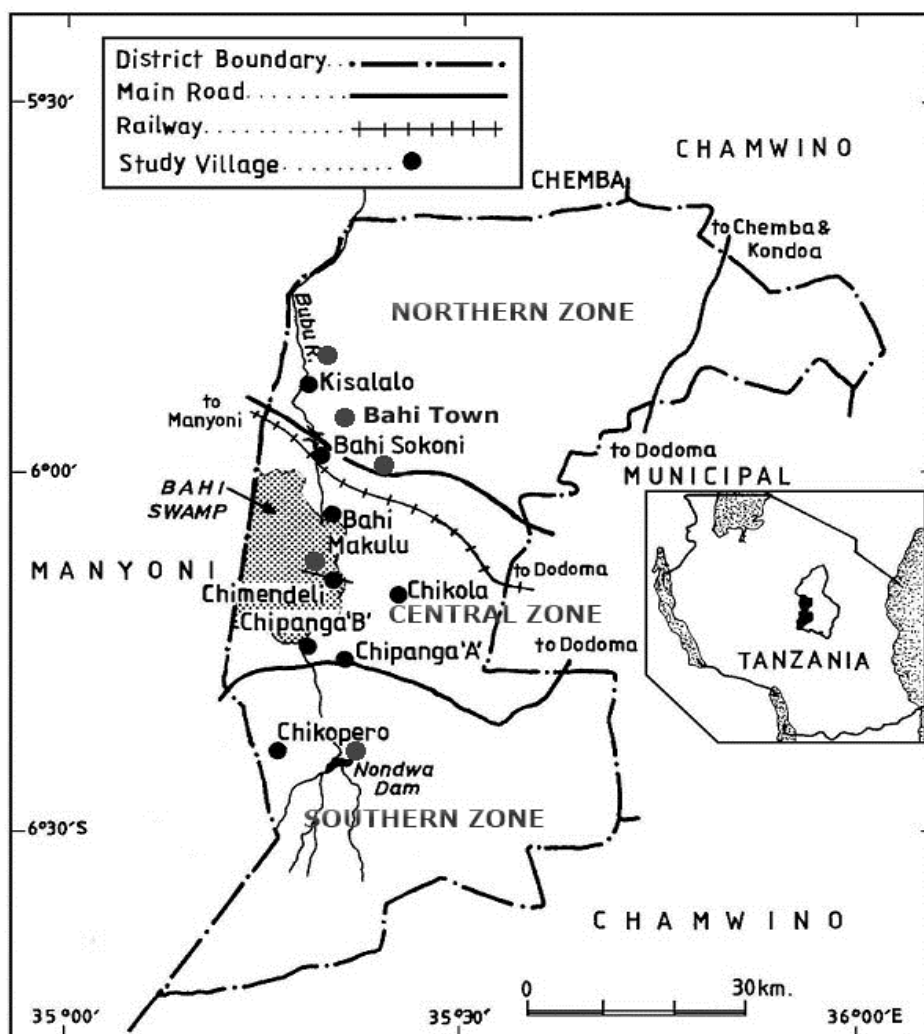

Fig. 1. A map showing the sampling locations in Bahi district

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Table 1.1. Activity concentration with their total uncertainties in the soil samples from villages in the Northern Zone (NZ) together with the average activity concentration of the zone

Sample code	Activity concentrations (Bqkg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
KSF	31.39±0.62	35.39±0.65	734.08±7.90
KMF	34.90±0.69	41.88±0.77	728.38±7.86
BSR	34.13±0.68	28.57±0.56	541.84±5.82
BHT	46.60±0.92	107.36±1.79	1,384.75±14.92
BSP	51.22±1.02	37.82±0.73	634.96±6.84
BSF	31.04±0.62	30.03±0.55	1,320.79±14.19
BST	60.09±1.19	99.62±1.73	806.99±8.68
Mean	37.28±4.34	51.13±9.13	874.85±426.26
Range	(31-60)	(28-107)	(542-1385)

Table 1.2. Activity concentration with their total uncertainties in the soil samples from villages in the Central Zone (CZ) together with the average activity concentration of the zone

Sample code	Activity concentrations (Bqkg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
CNR	18.10±0.36	24.83±0.44	499.54±5.38
CNP	9.44±0.19	10.37±0.19	463.49±4.98
CNF	22.46±0.45	15.01±0.31	161.90±1.75
CBS	17.37±0.34	29.75±0.52	486.83±5.25
BMF	30.74±0.61	47.74±0.81	874.77±9.43
BMR	42.75±0.85	26.53±0.54	467.44±5.05
BMS	29.51±0.59	32.06±0.57	577.06±6.21
CBF	17.00±0.34	20.19±0.37	428.04±4.60
Mean±SD	23.42±3.70	25.81±4.06	494.88±69.21
Range	(9-43)	(10-48)	(162-875)

Table 1.3. Activity concentration with their total uncertainties in the soil samples from villages in the South Zone (SZ) together with the average activity concentration of the zone

Sample code	Activity concentrations (Bqkg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
CPS	9.19±0.18	17.22±0.29	288.87±3.11
CFK	30.07±0.60	34.49±0.62	192.91±2.07
CKA	13.00±0.27	30.97±0.51	448.89±4.84
CPR	23.18±0.46	26.27±0.48	289.55±3.11
CBS	20.38±0.41	21.55±0.40	278.17±3.00
CKS	69.38±1.38	132.11±2.25	578.76±6.24
CKZ	21.30±0.42	27.28±0.49	418.34±4.51
CAP	23.14±0.46	38.64±0.68	706.67±7.64
CSS	12.00±0.24	21.76±0.37	207.29±2.24
CKF	30.13±0.59	22.88±0.46	266.66±2.87
Mean±SD	25.18±5.40	37.32±10.73	367.61±53.27
Range	(9-69)	(17-132)	(193-707)

3.2.1 Bubu River

Table 1.5 shows the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in water samples collected from 4 different sampling points along the Bubu River. The values for ^{226}Ra were found to be below the detection limit (0.11 Bql^{-1}) of the system used in this study. The average values for ^{232}Th were about 86% and 84%, respectively lower than the values obtained from Mkuju and Kilowero Rivers of Likuyu Village [27]. Hence

Mkuju and Kilowero rivers collect more radionuclides than the Bubu River. This might be because river Mkuju and Kilowero flow directly through the Mkuju deposit area. Water from Bubu River is used for irrigation as well as domestic purposes. However, the levels for ^{226}Ra and ^{232}Th in these samples are below the guideline levels for radionuclides in drinking water (1.0 Bql^{-1} for ^{226}Ra and ^{232}Th) recommended by WHO [28].

3.2.2 Bahi swamp

Table 1.6 shows the activity concentrations of ^{238}Ra, ^{232}Th and ^{40}K from water samples collected from 3 different sampling points in the Bahi Swamp. The values for ^{226}Ra were found to be below the detection limit (MDL), the average value for ^{232}Th is 0.26 ± 0.007 Bql^{-1} in a range of 0-0.68 Bql^{-1}and that of ^{40}K is 3.29 ± 1.20 Bql^{-1} in a range of 1-5 Bql^{-1}. The activity concentrations of ^{232}Th and ^{40}K in a sample collected from BSS were found to be higher than those of the other two locations. Water from Bahi Swamp is not used for any domestic or irrigation purposes due to its salt contents. However the water from this swamp is used for salt production as well as for fishing activities.

3.2.3 Domestic water from ground water wells

For the domestic water wells, the results of the activity concentrations of ^{226}Ra, ^{232}Th as well as ^{40}K are summarized in Table 1.7. The values for ^{226}Ra were found to be below the minimum detectable limit in all samples analysed in this work. Samples BDW2 and BDW1 had similar concentration of ^{232}Th. The highest activity concentrations of both ^{232}Th and ^{40}K were found

in sample from BST located close to the rice farming fields. There is a possibility that the activity in this ground water is influenced as well by the radionuclides in phosphate fertilizer used in farming field.

El Arabi et al. [29] and Ajayi and Achuka [30] have reported elevated radioactivity concentrations of ^{226}Ra and ^{232}Th in ground water from Elba in Egypt and Ogun state, Nigeria. The values of ^{226}Ra in Elba and Ogun state were found to be 100 and 40 times, respectively more than the MDL of the system used in this study. The average value of ^{232}Th in this study was found to be about the same as the value reported in ground water in Elba and Ogun State.

Fig. 2 compares the mean activities of 226Ra, 232Th and 40K obtained in samples of water analysed in this study. The mean values of 226Ra of all water bodies were found to be below the detection limit of the system used in this study. The ground water wells had the highest concentration of 232Th (0.68 Bql-1) whilst Bubu River and Bahi swamp had similar values. The level in ground water is 3 times higher than the value obtained in samples from Bubu River and Bahi swamp.

Table 1.4. Comparison of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in the Soil samples under investigation with those from other places

Location	Activity concentrations (Bqkg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
	Mean (range)	Mean (range)	Mean (range)	
NZ	37 (9–60)	51 (28–107)	875 (542–1385)	Present study
CZ	23 (9-43)	26 (10-48)	495 (162-875)	Present study
SZ	25 (9-69)	37 (17-132)	368 (193-707)	Present study
Likuyu village, Tanzania	52	36	564	[12]
Mkuju, Tanzania	245 (132 – 316)	80 (39 – 114)	1407 (1169 – 1651)	[5]
Algeria	50 (2 – 110)	25 (2 – 140)	370 (66 – 1150)	[23]
Egypt	17 (6 – 120)	18 (2 – 96)	320 (29 – 650)	[23]
Cameroon	134 (8 – 276)	177 (32 – 357)	1482 (982 – 1872)	[24]
Poland	26 (5 – 120)	21 (4 – 77)	410 (110 – 970)	[26]
Namibia	25 (18 – 34)	35 (25 – 48)	518 (382 – 622)	[3]
World average	33 (16 – 110)	45 (11 – 64)	420 (140 – 850)	[23]

However, this value is lower than the guideline levels for radionuclides in drinking water recommended by WHO [28]. Similar observation was reported by Fernadez et al. [31] who revealed elevated activity levels in ground water flowing under uranium deposit of Spain.

Table 1.8 compares the average activity concentrations of [226]Ra and [232]Th of the domestic water in Bahi to that from other regions in the world. The values of [226]Ra in this study were below the MDL (0.11 Bql[-1]) of the system. This value was found to be about 2 times higher than the values reported in the drinking water in USA and Poland [32,33]. The value was found to be about the same as the values reported in drinking water in Mexico, China and France

[34-36]. However, this value was observed to be 100 times lower than the value reported from the ground water in Elba (Egypt) and 40 times lower than that of ground water in Ogun state in Nigeria [29,30]. The value was also found to be more than 100 time lower than the value obtained in the drinking water in Switzerland [37].

The average value of [232]Th in this study was found to be about the same as the value reported in ground water in Elba (Egypt) and Ogun State (Nigeria) [29, 30]. This value is higher than the values reported in Switzerland, USA, China Poland, and France [32,34,33,37,35]. However, the value was found to be lower than the value reported by Bituh *et al.* 2009 in Croatia [38,39].

Table 1.5. The activity concentrations in water from Bubu River in Bahi District (Bql[-1]±SEM)

Sample code	Activity concentrations (Bql[-1]) in water		
	[226]Ra	[232]Th	[40]K
BRT	< 0.11	0.260±0.002	1.45±0.02
BRB	< 0.11	0.080±0.004	< 1.01
BRM	< 0.11	0.260±0.003	1.84±0.02
BRK	< 0.11	0.430±0.002	3.15±0.03
Mean	< 0.11	0.260±0.003	1.61±0.02
Range		(0.080 - 0.430)	(< 1.01 - 3.15)
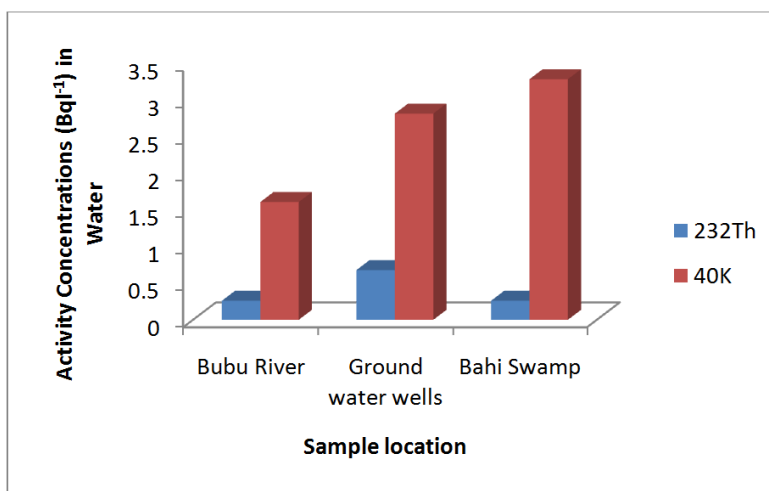
Fig. 2. The mean activity concentrations distribution of the three selected water bodies from Bahi District

Table 1.6. The activity concentrations distribution in water from Bahi swamp in Bahi District

Sample code	Activity concentrations (Bql[-1]) in water		
	[226]Ra	[232]Th	[40]K
BSS	< 0.11	0.68±0.01	4.99±0.05
BSM	< 0.11	0.100±0.003	0.97±0.01
BSU	< 0.11	< 0.07	3.92±0.04
Minimum		< 0.07	0.97±0.01
Maximum		0.68±0.01	4.99±0.05
Mean		0.260±0.007	3.29±0.03

Table 1.7. The activity concentrations distribution in selected domestic water wells from Bahi District

Sample code	Activity concentrations (Bql^{-1}) in water		
	^{226}Ra	^{232}Th	^{40}K
BDW2	< 0.11	0.65±0.01	3.21±0.03
BDW1	< 0.11	0.64±0.01	0.90±0.01
BST	< 0.11	0.74±0.03	4.36±0.05
Minimum		0.64±0.01	0.90±0.01
Maximum		0.74±0.03	4.36±0.05
Mean		0.68±0.02	2.82±0.03

Table 1.8. Comparison of average activity concentrations of ^{226}Ra and ^{232}Th in drinking water from the study with those from other regions

Region	Activity concentrations (Bql^{-1})		References
	^{226}Ra	^{232}Th	
Bahi	< 0.11	0.7000	Present study
USA	0.0018	0.0005	[32]
China	0.1200	0.0120	[34]
Poland	0.0045	0.0001	[33]
Switzerland	15.0	0.2000	[37]
Egypt (Elba)	1.6-11.1	0.21-0.97	[29]
Mexico	0.44	-	[36]
Nigeria	4.54	0.66	[30]
Croatia	0.09-6.2	0.023-3.5	[38]
France	0.7	0.0042	[35]
Romania	0.021	0.0093	[35]
Guidance Level	1.0	1.0	[28]

4. CONCLUSION

In this study γ-ray spectrometry was used to determine the radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in soil and water samples from Bahi wetlands. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil were found to be higher in the northern zone of the study area compared to the central and southern zones. The northern zone includes the Kisalalo uranium deposit of which exploration is still going on. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from northern zone were 37.3±0.7, 51.1±0.9 and 874.9±9.0 Bqkg^{-1}, respectively. The mean values for ^{226}Ra and ^{232}Th were slightly higher than the world average concentration values of ^{226}Ra (33 Bqkg^{-1}) and ^{232}Th (45 Bqkg^{-1}) reported by UNSCEAR (2000). However, these values were lower than the levels reported at Mkuju Uranium deposit in Tanzania. Samples collected from central and southern zones were within the range of the background activity reported in literature.

All the water samples analysed in this study had the activity concentration of ^{226}Ra below the MDL (0.11 Bql^{-1}) of the system used in this study. The MDL value is however lower than the permissible value of 1.0 Bql^{-1} for ^{226}Ra reported by WHO [28]. The value is also lower than the value reported in drinking water from Elba in Egypt, Ogun State in Nigeria, Switzerland, France, China and Mexico. The concentrations of ^{226}Ra in this study were also lower than the concentrations reported in Mkuju and Kilowero Rivers in Mkuju uranium deposit reported by Mwalongo [5] and Mohammed and Mazunga [12]. The results in this study have shown also that the ground water wells had the highest concentrations of ^{232}Th than the water collected from Bubu River and Bahi Swamp. This might be because ground water is from deeper aquifers [30].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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