Assessment of natural radioactivity levels and radiation hazards in shore sediments from the Zambezi River, Namibia

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ARTICLE INFO

Article history:
Received: 24 June 2019
Received in revised form: 15 August 2019
Accepted: 6 September 2019
Published: 4 November 2019
Edited by KC Chinsembu

Keywords:
Radioactivity
Radiological hazards
Gamma ray spectrometer
Zambezi River

ABSTRACT

In this study, the radioactivity concentrations and the potential health hazards of primordial radionuclides; ^{238}U, ^{232}Th and ^{40}K were measured using a gamma ray spectrometer in 30 soil samples collected from the Zambezi River, Namibia. The average activity concentrations for ^{238}U, ^{232}Th and ^{40}K was found to be 18.91 Bq/kg, 15.58 Bq/kg and 79.17 Bq/kg respectively. The activity concentrations of the measured radionuclides were used to calculate the radiological hazards in soil samples i.e. absorbed dose rate, annual effective dose equivalent, radium equivalent activity and hazard indices (H_{ex} and H_{in}). From the values obtained, all the radiological hazard parameters were within the world acceptable average values. However, the mean annual effective outdoor and indoor dose equivalent was found to be 0.26 mSv/y and 1.05 mSv/y, respectively, which both exceed the recommended world average United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) values of 0.07 mSv/y for outdoor and 0.45 mSv/y for indoor.

1 Introduction

Radiation is around us and has always been present; therefore, there is an increased concern on the impacts it has on human health [1]. Radiation exposure is mainly through natural and artificial sources. The main radionuclides which are significant from a radiological point of view are the primordial radionuclides (^{238}U, ^{232}Th and ^{40}K and their progeny) and these are responsible for the generation of external gamma radiation. External gamma radiation which arises from Naturally Occurring Radioactive Materials (NORM) widely distributed in the earth's crust contributes more than 50% to the collective radiation dose received by the world population [2]. It is well documented that the major pathway for human exposure to ionising radiation from terrestial radiation is through the ingestion of radionuclides in food, water and soil, dermal contact with the skin, and to a large extent the inhalation of radon and its progenies [3]. Human activities such as the use of fertilizers for agricultural purposes, mining and milling, processing Uranium ores and mineral sands and burning of fossil fuels may increase the level of NORM in the environment [4].

According to review on ionizing radiation of the UK population report, natural radiation accounts for up 85% of the annual dose received by the world population in which 18% comes from buildings, 14% comes from cosmic, 42% comes from radon and 11% comes from food and drinking [5] The report further confirms that exposure to

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natural radiation is in most cases, of little radiological concern to members of the public except those who are working with mineral ores and naturally occurring radioactive material (NORM) [6]. However, this affirmative contradicts the assertion given by World Nuclear Association which states that any dose involves a possible risk to human health [7] even though the level of individual exposure to NORM is usually statistically insignificant on an individual basis, from a health physics point of view. Certain levels of radiation exposure are permissible, but excessive exposure can be harmful and may be fatal; it is for this reason that it is important to assess activity concentrations and radiation hazards of natural radionuclides in order to determine radiological risks [8].

The Zambezi River situated in North Eastern Namibia is a major recreational area because of its serenity and wildlife reserves. Agricultural farming is a common practice in areas near the river and shore sediments are often used as building material. Studies on radioactivity in soil have been conducted in other parts of Namibia [4, 9, 10] but there is limited knowledge on the level of radionuclides in shore sediments from the Zambezi River. This study provides baseline information on the natural radioactivity levels and potential radiological hazards in shore sediments from the Zambezi River, Namibia.

2 Materials and methods

2.1 Study area

The Zambezi River is located 17°27′59.99″S and 24°17′60.00″E and has a fair catchment area which receives good rainfall than the rest of the country rivers. The river covers approximately 150 km length along the Namibia-Zambia border. Katima Mulilo is the nearest town to the river and has a total population of 28362 residents [11]. The main activity along the Zambezi river is Agricultural farming which is being promoted due the abundance of rainfall. Also, communities residing near the river make use of soil sediments as building material to make traditional huts. Vast areas along the river are nature conservation areas with scenery game resorts, making it a major recreational area and holiday destination for tourists [12].

Figure 1: Map showing the study area (Zambezi River) [13].

2.2 Sample collection

A total of thirty (30) soil samples were purposefully sampled at 7-10 m away from the river tide to represent points were human activities takes. At each sampling site, triplicate samples were collected and thoroughly mixed to make one representative of the area. The sampling points were clearly marked using Global Positioning System (GPS). At each point, debris was cleared, and shore sediments were taken using a hand scooper at a depth of about 10 cm. Sediments were placed in polythene bags and labelled according to the Geographical positioning points (GPS coordinates) as shown Figure 1. Each plastic bag was then sealed to avoid cross contamination during transportation.

2.3 Sample preparation for counting

The samples were analysed at the Namibia University of Science and Technology Physics laboratory. At the laboratory, all investigated samples were oven-dried at $115°C$ for about 24 hours to eliminate any presence of water. Each sample was passed through a 2 mm sieve to obtain homogeneous samples. For the measurement of natural radioactivity, samples were weighed, and 500 g of each sample was placed in labelled a Marinella beaker which were then hermetically sealed to prevent radon gas and its progeny from escaping. The samples were firmly sealed and stored for 30 days to ensure a state of equilibrium is established between ^{238}U, ^{232}Th and their respective daughters [14].

2.4 Activity concentrations

After attaining secular equilibrium, each sample was counted for 6 hours in a co-axial n-type Canberra Gamma Spectrometry-HPGe detector (Model: GC4520, Serial number: 10882) with a resolution of 2.0 keV at 1332 keV of 60Co with a relative efficiency of 45%. The detector was calibrated for both energy and efficiency. To minimise the effects of background radiation, the HPGe detector was lead shielded. The data acquisition and identification of gamma-rays of product radionuclides were performed via Genie 2000 software.

2.4.1 Energy and Efficiency Calibration of the detector

Gamma ray spectrometry system was calibrated using an IAEA composite reference radioactive sources: ^{60}Co, ^{88}Y, ^{85}Sr, ^{57}Co, ^{113}Sn and ^{137}Cs with at least three peaks which had gamma energy range to include all the analysed radionuclides in the samples. The efficiency calibration was carried out to obtain accurate results for gamma-ray spectrometry of the unknown radioactivity levels in samples using equation (1). Equation (1) defines the absolute full-energy peak efficiency.

$$\varepsilon_f = \frac{N_p}{N_\gamma} \tag{1}$$

where ε_f is the full-energy peak efficiency which represents the number of counts detected for every number of gamma-ray emitted by the source, N_p is the net gamma-ray count rate in the full-energy peak and N_γ is the rate at which gamma-rays are emitted and is expressed mathematically by equation (2).

$$N_\gamma = AP_\gamma \tag{2}$$

where A is the number of nuclear decays per second and P_γ is the probability per nuclear decay [9].

2.4.2 Activity concentrations

Since secular equilibrium was attained between ^{238}U and ^{232}Th and their progeny, the activity concentrations of ^{238}U and ^{232}Th was determined by considering the average energy peaks of their daughter nuclides while the activity concentration of ^{40}K was determined from its 1460.83 keV gamma-ray energy peak [15]. The activity concentrations were calculated using equation (3) [16].

$$A = \frac{N}{E_\gamma S_\gamma T_s M} \tag{3}$$

where N is the net number of counts under the resulting photon peak, E_γ is the efficiency of the specific gamma ray, S_γ is the emission probability of the corresponding gamma-ray energy, T_s is the sample counting time in seconds and M is the mass of the sample in kg.

2.5 Calculation of radiological hazards

2.5.1 Absorbed dose rate (D)

The radiological effects depend greatly on the absorbed dose rate in air at 1.0 m above ground level [17]. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K was used to calculate the Absorbed dose rate (ADR) in the air by applying factors: 0.462, 0.604 and 0.0417, respectively, and this is shown in equation (4) [19, 20].

$$ADR(nGy/h) = (0.462C_U + 0.604C_{Th} + 0.0417C_K) \tag{4}$$

where, C_U, C_{Th} and C_K represents the activity concentration in Bq/kg of ^{238}U, ^{232}Th and ^{40}K, respectively.

2.5.2 Annual effective dose equivalent (AEDE)

Since the absorbed dose rate represent the amount of energy deposited per unit mass and is applicable to air and this is not sufficient to express the health risk human populations are exposed to in various organs, another term known as the effective dose was introduced which takes into account the dose received by human population to various organs. The term utilised a conversion coefficient from absorbed dose in the air to effective dose for both outdoor and indoor occupancy factor. For calculation purposes, a conversion coefficient of 0.7 Sv/Gy was employed to convert the absorbed rate in air to annual effective dose with an outdoor occupancy factor of 0.2 and an indoor occupancy factor of 0.8 [18]. This is expressed as;

$$H_E = D \times T \times F \tag{5}$$

where H_E is the annual effective dose (mSv), D is the absorbed dose rate (nGy/h), T is the outdoor occupancy time $(365\,\text{days} \times 24\,h \times 0.2)$ and $(365\ \text{days} \times 24\,h \times 0.8)$ for indoor occupancy, and F is the conversion factor $(0.7 \times 103$ mSv/109 nGy).

2.5.3 Radium Equivalent Activity ($\mathrm{Ra_{eq}}$)

Since primordial radionuclides ^{238}U, ^{232}Th and ^{40}K are not evenly distributed in soil sediments, it is not convincing to assess radiation hazards relating to soil sediments by considering the effective dose only. Radiological effects should be expressed taking into consideration the hazards relating to all the primordial radionuclides. To estimate exposure uniformly, the radionuclide concentrations are defined in terms of 'Radium equivalent activity' ($\mathrm{Ra_{eq}}$) in Bq/kg. Radium equivalent is defined as the weighted sum of activities of primordial radionuclides [19].

$$\mathrm{Ra_{eq}}\,(\mathrm{Bq/kg}) = C_U + 1.43C_{Th} + 0.077C_K \tag{6}$$

where,C_U, C_{Th} and C_K represents the activity concentration in Bq/kg of ^{238}U, ^{232}Th and ^{40}K, respectively. The equation is based on the theory that 259 Bq/kg of ^{232}Th, 370 Bq/kg of ^{238}U and 4810 Bq/kg of ^{40}K produce the same gamma dose rates. The allowable highest value of radium equivalent activity is 370 Bq/kg which agrees with the dose limit of 1.0 mSv for the general population [20].

2.5.4 The Hazard Indices ($\mathrm{H_{ex}}$ and $\mathrm{H_{in}}$)

Hazard indices were introduced to ensure that exposure does not exceed the allowable equivalent dose of 1 mSv/y [10]. The external hazard index was calculated as;

$$\mathrm{H_{ex}} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \tag{7}$$

Alternatively, the internal exposure due to radon and its short-lived daughters is given by the internal hazard index ($\mathrm{H_{in}}$) [17] and was calculated as;

$$\mathrm{H_{in}} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \tag{8}$$

where, C_U, C_{Th} and C_K represents the activity concentration in Bq/kg of ^{238}U, ^{232}Th and ^{40}K, respectively. In order to neglect radiological effects on the human population, both $\mathrm{H_{ex}}$ and $\mathrm{H_{in}}$ must be less than unity [21].

3 Results and discussion

3.1 Activity concentrations

The activity concentrations of the radionuclides ^{238}U, ^{232}Th and ^{40}K detected in the sediment samples collected from Zambezi river basin are listed in Table 1. As can be seen Table 1, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K varies from 7.36 to 34, 5.32 to 54.30 and 5.06 to 145.77 Bq/kg with mean of 18.91, 15.58 and 79.17 Bq/kg respectively. The activity concentrations varied in spatial and temporal because the river bottom can show large variations in chemical and mineralogical compositions due to rare-earth elements [22].

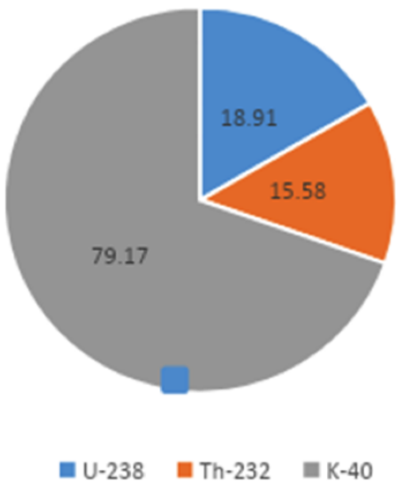

Figure 2: The distribution of mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the samples collected from Zambezi river basin.

Table 1: The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in shore sediments collected from various sampling points

Sample ID	Activity Concentrations (Bq/kg)		
	^{238}U	^{232}Th	^{40}K
K1	26.39	17.98	102.17
K2	14.38	58.30	64.62
K3	14.38	9.39	56.62
K4	26.40	37.48	153.06
K5	17.61	9.95	56.26
K6	17.02	10.97	68.16
K7	11.78	7.10	13.46
K8	8.99	5.32	5.06
K9	16.82	10.65	56.48
K10	12.45	7.99	47.84
K11	22.55	15.87	86.86
K12	27.58	18.19	109.75
K13	31.68	26.73	145.77
K14	13.35	8.35	44.81
K15	20.44	13.92	80.96
K16	17.74	10.91	56.86
K17	14.66	10.52	68.18
K18	17.68	11.19	73.83
K19	12.40	7.86	53.47
K20	10.54	12.92	70.57
K21	18.54	13.03	86.03
K22	17.28	11.54	79.56
K23	24.45	17.71	103.81
K24	14.37	10.38	65.56
K25	7.36	5.34	51.00
K26	19.95	14.30	97.55
K27	16.37	10.93	73.68
K28	30.18	25.82	143.52
K29	34.72	24.44	122.54
K30	29.02	22.14	137.08
Minimum	7.36	5.32	5.06
Maximum	34.72	58.30	145.77
Average	18.91	15.58	79.17

In comparing the results of this study with the worldwide average concentrations, it can be observed that the results compare well with earlier reports by [19], with values of 35 Bq/kg for ^{238}U, 30 Bq/kg for ^{232}Th and 400 Bq/kg. These results are also in agreement with previous similar studies carried out in Erongo region by [9]. Figure 2 also shows the percentage distribution of the measured radionuclides in the shore sediments collected from Zambezi river basin. It is worth noting that the activity concentrations of ^{40}K is higher than that of ^{238}U and ^{232}Th in all the sampling sites in shore sediments and this can be attributed partly to the use of agrochemicals such as fertilizers for agricultural practices in the study area and partly due to to the presence of loamy and clay sediments [23].

3.2 Radiological hazards

The activity concentrations in the shore sediments samples collected was used to calculate the Absorbed dose rate (ADR), Annual effective dose equivalent (AEDE), Radium equivalent activity concentrations ($\mathrm{Ra_{eq}}$) and radiological hazard indices ($\mathrm{H_{ex}}$ and $\mathrm{H_{in}}$) and the results are presented in Table 2. As can be observed from Table 2, the absorbed dose rate (ADR) in air 1.0 m above the ground, Annual outdoor effective dose equivalent (AEDEout), the annual effective indoor dose equivalent (AEDE), the radium equivalent activity concentrations ($\mathrm{Ra_{eq}}$), the external radiation hazard ($\mathrm{H_{ex}}$) and the internal radiation hazard ($\mathrm{H_{in}}$) varied from 7.58 to 44.67 nGy/h, 0.09 to 0.55 mSv/y, 0.37 to 2.19 mSv/y, 16.99 to 102.98 Bq/kg, 0.05 to 0.28 and 0.07 to 0.32, with mean of 21.45 nGy/h, 0.26 mSv/y, 1.05 mSv/y, 47.28 Bq/kg, 0.13 and 0.18, respectively. The average value for the absorbed dose rate was lower than the world average value of ~ 51 nGy/h [18].

Table 2: A summary of the radiological parameters (**ADR, AEDE**, $\mathbf{Ra_{eq}}$, $\mathbf{H_{ex}}$ and $\mathbf{H_{in}}$) due to exposure to ^{238}U, ^{232}Th and ^{40}K in the measured from the shore sediment samples

	ADR (nGy/h)	$\mathbf{AEDE_{(Out)}}$ **(mSv/y)**	$\mathbf{AEDE_{(In)}}$ **(mSv/y)**	$\mathbf{Ra_{eq}}$ **(Bq/kg)**	$\mathbf{H_{ex}}$	$\mathbf{H_{in}}$
Minimum	7,58	0,09	0,37	16,99	0,05	0,07
Maximum	44,67	0,55	2,19	102,98	0,28	0,32
Average	21,45	0,26	1,05	47,28	0,13	0,18

However, it should be noted that the average annual effective outdoor dose rate is three times higher and the annual effective indoor dose twice higher than world average values as listed in UNSCEAR 2000, with values of 0.07 mSv/y ($\mathrm{AEDE_{out}}$) and 0.45 mSv/y ($\mathrm{AEDE_{in}}$) [18]. The radium equivalent ($\mathrm{Ra_{eq}}$) value is one of the most important parameters to evaluate the radiological risk to the general population and in this study, the calculated mean radium equivalent activities of the sediments samples were significantly below the recommended value of 370 Bq/kg as in [20] as illustrated in Figure 3.

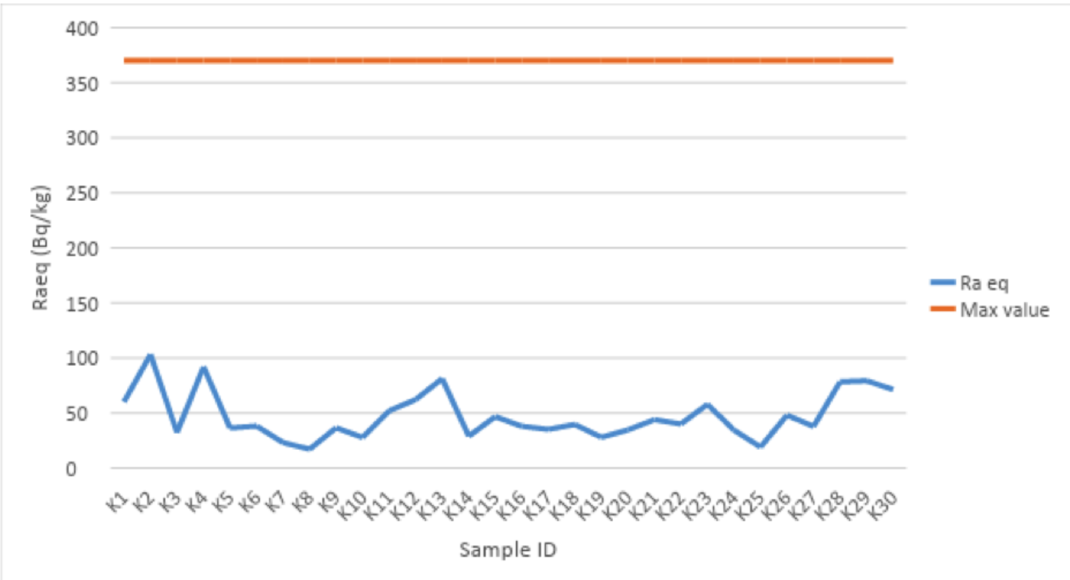

Figure 3: Comparison of the radium equivalent activity ($\mathrm{Ra_{eq}}$) with the recommended maximum value.

On the other hand, the external hazard index (H_{ex}) and the internal hazard index (H_{in}) in all the 30 samples collected from the Zambezi river basin are within the safe limit i.e. the value must be less than 1 and these results are in agreement with results conducted by Abba in the same geographical locations. The Hex and Hin were less than unity which is a conservative figure set out by Recommendations of the International Commission on Radiological Protection (ICRP) [24, 25] for radiological protection purposes. Since the radiological parameters are within the safe limit, the sediment samples does not pose a significant threat to the public even when utilised as a building material.

4 Conclusion

The activity concentrations and radiological hazard associated with shore sediment samples collected from Zambezi river basin were investigated in this study. The results indicated that only primordial radionuclides were present in the samples. The activity concentrations for ^{238}U, ^{232}Th and ^{40}K is within the world average values while the average absorbed dose rate, radium equivalent activity and hazard indices are all within the permissible level. In contrast to other radiological parameters, the mean AEDE in shore sediments is higher than the world average values: AEDE out with value of 0.07 mSv/y and AEDE in with value of 0.45 mSv/y [26]. Since most of the radiological parameters are within the safe limits, the probability of radiological impact on the inhabitants/ public living and using the sediment samples in this area will be insignificant and there is very little chance of radiological health effect on these people or even tourists.

Acknowledgements

The authors extend their gratitude to Namibia's University of Science and Technology for assisting with the gamma spectrometry analysis. Further acknowledgment goes to Mr. Markus Hitila for analysing the samples and Mr. Tangeni Mukete for his assistance in sample collection.

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