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Assessment of terrestrial radionuclides in the sandy soil from Guliakhali beach area of Chattogram, Bangladesh

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Abstract
A study was conducted to assess the concentrations of primordial radionuclides in fifteen sandy soil samples collected from a newly discovered Guliakhali sea beach in Bangladesh by HPGe gamma-ray spectrometry. The specific activity of soil samples varied from 25 ± 3 to 130 ± 11 Bqkg^{-1}, from 15 ± 2 to 70 ± 6 Bqkg^{-1} and from 200 ± 16 to 880 ± 43 Bqkg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively. Although a few samples showed comparatively higher radiation level and associated doses possibly because of the ship breaking industry located nearby, overall, most of the values of annual effective dose are less than the worldwide average value of 1 mSvy^{-1}.

Keywords Natural radioactivity · Sandy soil · HPGe detector · Effective dose · Radiation hazard indices

Introduction

Low-level ionizing radiation is ubiquitous in our dwelling environment, and exposure to such radiation is unavoidable by living beings [1]. The utilization of soil, the surface material that forms the uppermost layer of earth and one of the principal substrata of life on earth, in various spheres of life is considered as the major pathway of gamma-ray exposures to human health [2]. The investigation of the dispersion of radioactive segments in the soil is imperative to comprehend the radioactivity level in any territory. Specifically, it is likewise critical to assess the radiation danger arising from the exposure of gamma-beam to the human body. Raised levels of natural radionuclides in soil and other dwelling media may introduce extra radiation doses to human bodies [3].

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Prolonged exposure to an elevated level of radiation can cause acute health effects such as radiation sickness or long-term health effects such as cardiovascular disease [4]. Many studies demonstrated the non-linear effects of radiation exposure to human health using the framework of the linear no-threshold (LNT) model. The current principle of radiation exposure to the occupational workers is 'as low as reasonably achievable (ALARA)', however, the total dose should not exceed 50 mSvy^{-1} [5]. On the other hand, an amount of 2.4 mSvy^{-1} has been reported as the average radiation dose received by a person from natural sources of radiation including cosmic radiation, radon, and any medical radiation according to the UNSCEAR [6] report. However, according to the LNT model, there is still non-negligible uncertainty on the health effects of radiation, which may involve some carcinogenic risk even at the levels of natural background.

Measurement of radioactivity in soil, sand, and sediment samples in sea beaches in Bangladesh such as Kuakata, Cox's Bazar, Saint Martin, and Potenga was performed by several researchers in recent decades [7–11]. However, there is no radioactivity data available in the Guliakhali sea beach area of Chattogram district in Bangladesh. Moreover, the present study area is located very close to the 'ship breaking industry', one of the most hazardous industrial activities, and is operating for several decades [12]. It is one of the largest ship breaking yards in the world and receives criticism for

contaminating the coastal environment of Bangladesh. It is presumed that these ship scrapping activities may contribute Technologically Enhanced Naturally Occurring Radioactive Materials (TENORMs) in this or peripheral area. Therefore, an assessment of Naturally Occurring Radioactive Materials (NORMs) in the environmental media of the Guliakhali beach and surrounding area is required to ensure the safety of public health and furthermore for the vacationers who visit this spot reliably due to its normal excellence, sporting movement and investing relaxation energy.

The goal of this investigation is to measure the prevailing concentrations of primordial radionuclides ^{40}K, ^{226}Ra, ^{232}Th in the sandy soil of the examination territory which is Guliakhali sea beach located at Chattogram district in Bangladesh, and to evaluate the radiation risk to the concerned population by calculating the radiation hazard parameters. In this way, the measured radioactivity in the sandy soil may assist us to know the radiological safety standard of the area as well as the foodstuffs produced from this area. Moreover, this study may also contribute to establish baseline data which is important for Bangladesh, because the country's first nuclear power plant is now under construction and expected to go into operation in 2023–2024 [13].

Materials and methods

Description of the study area

The study area 'Guliakhali sea beach' is a muddy beach situated at the west-southern part of Sitakunda upazila at Chattogram district, Bangladesh. Due to its coastal scenic beauty and easy access from the major cities including the capital of Bangladesh, in recent times, this place is receiving greater attention from both local and regional tourists. The entire area is secured by a meager layer of topsoil. Human habitation in the area is moderate. The geographical characteristics of southeastern Bangladesh including the study area is shown in Fig. 1. The global position of this area is around 22°36′51″ NL and 91°38′58″ EL. Sitakunda upazila had a population of 335,178 (in 2018 survey), it occupies an area of 483.97 km^2 [14], and currently possesses the population density of almost 1,200/km^2.

Sample collection and preservation

Fifteen (×3) sandy soil samples were collected randomly from fifteen different locations of Guliakhali area in September 2018. The sampling points of the study area are shown in Fig. 1. Approximately 1 kg (wet weight) of samples were collected at 0–5 cm depth from each location. The sampling points were identified using an online satellite map before starting the collection of samples. Global Positioning System (GPS) was used to record the sampling locations. The samples were collected from the node points of the square grids with a distance of ~ 50 m. Collected samples were kept in clean plastic packets/bags, marked properly, and transported to the laboratory for analysis. The samples collected were appropriately coded and standard quality control procedures were maintained according to International Atomic Energy Agency (IAEA) guidelines during sampling, sample preservation, and processing [15] which is shown in Fig. 2.

Sample preparation

After the collection, unwanted materials, for example, stones, roots, and vegetation were isolated from the soil samples. The samples were first dried under the sunlight,

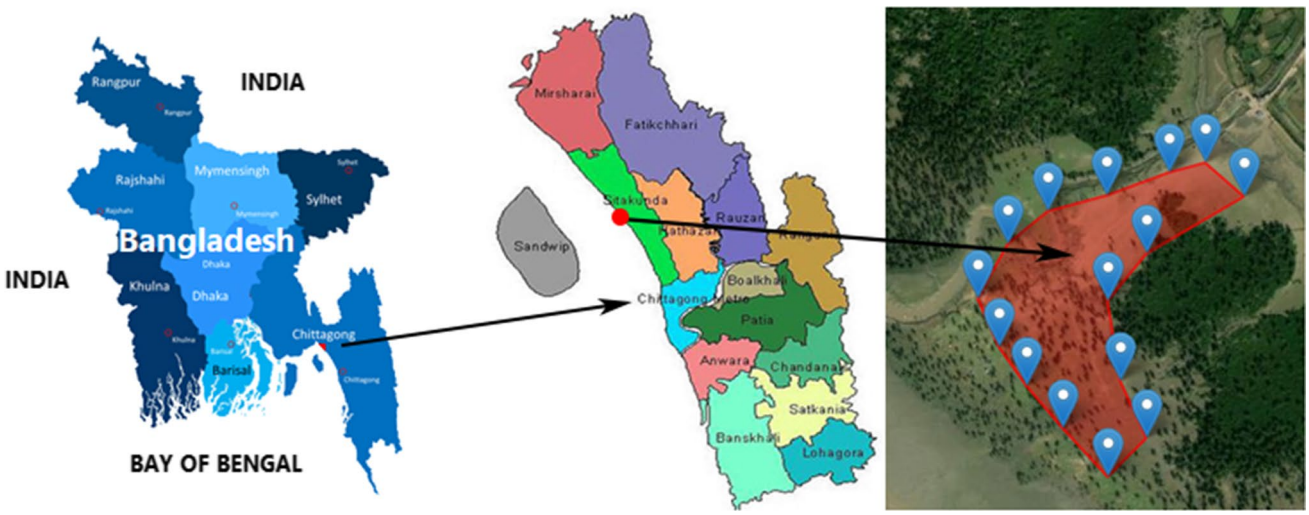

Fig. 1 The geographic location of Guliakhali Sea Beach in the south-eastern part of Bangladesh

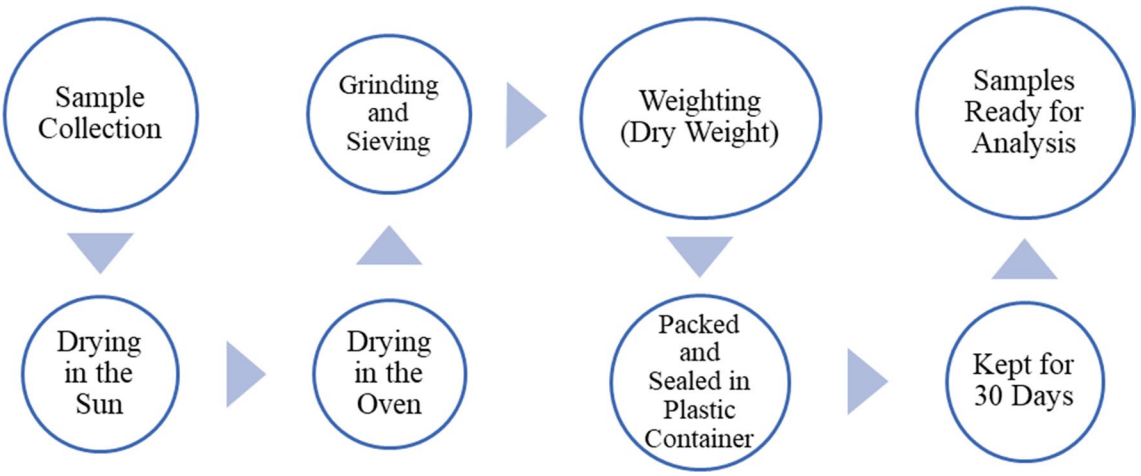

Fig. 2 Sample processing flowchart

subsequently crushed with mortar and pestle, homogenized, screened with a test sifter of opening 425 µm. The weight of each sample was about 500 g. All the samples were packed individually into cylindrical plastic containers, sealed tightly, and kept at room temperature for 28 days to ensure that ^{226}Ra and ^{232}Th were in secular equilibrium with short-lived daughter products [16, 17].

Measurement system

A number of analysis systems exist which are able to determine the radionuclide contents of various types of samples and geometry. For all types of samples, gamma-ray spectrometry is generally the most effective technique to analyze the gamma-emitting radionuclides in these samples. A coaxial, high-resolution HPGe gamma-ray spectrometer coupled with associated electronics including digital spectrum analyzer (DSPEC jr 2.0) was used for measurement of radionuclides concentration in the sample. The detector was housed with a cylindrical lead shielding arrangement having a fixed bottom and a movable cover to suppress the background contribution from the surrounding environment. The energy resolution of the detector is a measure of the sharpness of a photo-peak and it determines the ability of a detector to separate or distinguish the presence of two gamma rays closely spaced in energy. The energy resolution of the 1.33 MeV energy peak for ^{60}Co was found to be 1.69 keV at full-width half-maximum with a relative efficiency of 19.6%.

Energy and efficiency calibration

It is essential that energy and efficiency calibration of the detector be performed with great care because the accuracy of the measured data largely depends on these factors. The energy calibration of the detector was completed using standard point sources such as ^{22}Na, ^{57}Co, ^{60}Co, ^{133}Ba, ^{137}Cs, etc. The efficiency of a detector is a measure of the number of radiation quanta (particles or photons) detected by it from the total number of emitted radiation quanta by the source. In order to determine the detector efficiency, a standard source was made by mixing ^{152}Eu of known activity (Liquid form, 100 Bq activity) with Al_2O_3 matrix, prepared in identical containers to the samples. The efficiency data was also checked using the IAEA reference samples RGU-1, RGTh-1 and RGK-1 IAEA, [18]. The well-known Eq. (1) was used to determine the efficiency of the detector [19]:

$$Efficiency = CPS/(DPS \times I_{\gamma}) \quad (1)$$

where, CPS = Counts per second for the radionuclides of interest present in the standard sample, DPS = Disintegration per second, and I_{γ} = γ-ray intensity of the source. The counting efficiency curve of the HPGe detector was drawn and shown in Fig. 3.

Measurement of radioactivity

The activity concentration of ^{226}Ra was calculated through characteristic gamma lines of 241.98 keV, 295.21 keV and 351.92 keV of ^{214}Pb and 609 keV, 1120.3 keV and 1764.5 keV of ^{214}Bi. ^{232}Th activity was calculated through 583.14 keV of ^{208}Tl, 911.07 keV and 969.11 keV of ^{228}Ac, respectively [15]. For an accurate evaluation of ^{226}Ra and ^{232}Th radioactivity, a weighted mean approach was adopted [19, 20]. The radioactivity of ^{40}K was calculated through singly occurring characteristic 1460.75 keV gamma line. The radioactivity concentration of each radionuclide was calculated using the following equation [17, 21]:

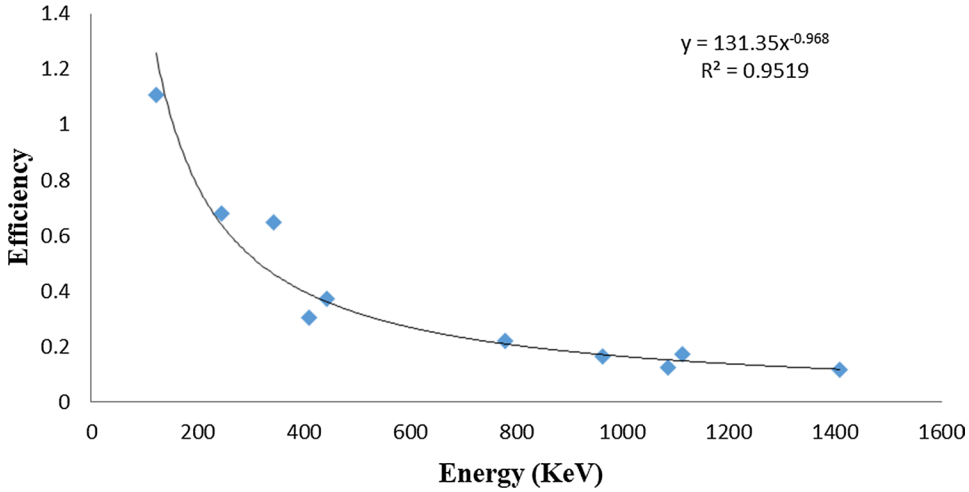

Fig. 3 Efficiency curve of the HPGe detector for solid matrix

$$A_i = \frac{cps}{\varepsilon \times I_\gamma \times w} \quad (2)$$

where A_i is the activity concentration of each radionuclide in the sample; cps is the net count rate per second, which is obtained by subtracting the background count from the samples radionuclide activity counts; ε is the efficiency of the detector at specific gamma-ray; I_γ is the transition probability of the specific gamma-ray, and w is the mass of the sample (kg).

The uncertainty of the measured radioactivity was obtained by using the uncertainty propagation law of the relevant quantities expressed in Eq. (2). The mathematical formulation is expressed in Eq. (3) [16]:

$$\text{Combined Standard Uncertainty} = A_i \times \sqrt{\left(\frac{u(N)}{N}\right)^2 + \left(\frac{u(T)}{T}\right)^2 + \left(\frac{u(I_\gamma)}{I_\gamma}\right)^2 + \left(\frac{u(w)}{w}\right)^2 + \left(\frac{u(\varepsilon)}{\varepsilon}\right)^2} \quad (3)$$

where, N, T, I_γ, w and ε are the sample counts, counting time, gamma-ray emission probability, sample weight, and counting efficiency, respectively. The term u(N), u(T), u(I_γ), u(w), and u(ε) are respective uncertainties due to counting statistics (1–12%), measurement time (1%), gamma-ray emission probability (< 1%), sample weight (1%), and efficiency of the detector (5%). The overall uncertainties show a range of 5–13%, presented in Table 1 along with the measured activity of the radionuclides of interest.

Determination of MDA

The minimum detectable activity (MDA) of the used system was determined using the Eq. (4) as reported in [22]:

$$\text{MDA} = \frac{K_\alpha \times \sqrt{B}}{\varepsilon \times I_\gamma \times T \times w} \quad (4)$$

where, K_α is the statistical coverage factor having a value of 1.64 (at the 95% confidence level), B is the number of background counts for the corresponding radionuclide, ε, I_γ, T, and w (in kg) have their usual meaning similar to Eq. (3). The MDAs were found to be 0.35 Bqkg^{-1} for ^{226}Ra, 0.64 Bqkg^{-1} for ^{232}Th, and 2.2 Bqkg^{-1} for ^{40}K.

Calculation of absorbed dose rate

Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the soil. The absorbed dose rate in the air at 1 m above the ground surface due to the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil was estimated using the formula given in UNSCEAR [6, 23]:

$$D_{out}(nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.042A_K \quad (5)$$

where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1} respectively.

Calculation of outdoor annual effective dose

The outdoor absorbed dose rate was converted into outdoor annual effective dose by using a conversion factor of 0.7 SvGy^{-1} recommended by the UNSCEAR [6] and 0.2 for the outdoor occupancy factors by considering that the people on an average, spent 20% of their time in outdoors [17, 24]:

$$E_{out}(mSvy^{-1}) = D \times 24 \times 365.25 \times 0.2 \times 0.7 \times 10^{-6} \quad (6)$$

where D is the outdoor absorbed dose rate in the air ($nGyh^{-1}$), 8760 is the time in hours for one year, 0.2 is the outdoor occupancy factor, and 0.7 $SvGy^{-1}$ is the quotient of effective dose equivalent rate to absorbed dose rate in air, and 10^{-6} is the factor converting nano-to-milli.

Excess lifetime cancer risk

Consequent upon the evaluation of AEDE (Outdoor Annual Effective Dose Equivalent), the excess lifetime cancer risk (ELCR) has been estimated using the equation [25]:

$$ELCR = AEDE \times DL \times RF \quad (7)$$

where AEDE, DL and RF are the outdoor annual effective dose equivalent, duration of life (70 years) and risk factor ($0.05\ Sv^{-1}$), respectively. The risk factor is fatal cancer risk per sievert, which is assigned to a value of 0.05 for the public for stochastic effects [25].

Results and discussion

The activity concentrations in the sandy soil samples collected from 15 different places are reported in Table 1, and Fig. 4 shows the fluctuations of radioactivity level of the radionuclides.

The mean values of ^{232}Th and ^{40}K are found to be lower than the population-weighted world average values of 32 and 420 $Bqkg^{-1}$ respectively, while the mean value of ^{226}Ra exceeded the world average of 45 $Bqkg^{-1}$ [6]. Conveyances of common radionuclides in the soil rely upon their physical, substance and land properties. The relatively high radiation level found in this area may be due to the presence of a few heavy minerals as placer deposits. Several samples show relatively higher values of ^{40}K, and this may be attributed to agricultural runoff the chemical fertilizer as well as the considerable abundance of elemental potassium in seawater. The regular tidal waves may mediate in the transportation and deposition of radioactive-, trace-, and toxic metals in the peripheral coastal strips. However, there is no attendance of ^{137}Cs which indicates the absence of any unwanted nuclear relevant activities nearby the study areas.

Table 1 Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in all soil samples

Sample ID	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)
1	30 ± 4	35 ± 3	220 ± 16
2	25 ± 3	20 ± 3	225 ± 17
3	60 ± 5	15 ± 2	435 ± 29
4	40 ± 4	25 ± 3	420 ± 27
5	60 ± 5	25 ± 3	200 ± 16
6	90 ± 7	30 ± 3	425 ± 28
7	55 ± 4	55 ± 5	720 ± 31
8	50 ± 4	20 ± 2	565 ± 30
9	40 ± 4	25 ± 3	450 ± 28
10	45 ± 4	70 ± 6	350 ± 26
11	80 ± 6	20 ± 2	320 ± 18
12	130 ± 11	60 ± 5	880 ± 43
13	55 ± 4	15 ± 2	295 ± 17
14	55 ± 2	30 ± 3	425 ± 28
15	25 ± 3	20 ± 2	255 ± 18
Range	25–130	15–70	200–880
Mean	56 ± 5	31 ± 3	412 ± 25

Table 2 shows the comparison of the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K among different places of the world [26–38].

A comparison of the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for the analyzed samples with the available literature is presented in Table 2. It shows that measured concentration of ^{226}Ra in our study area is above the data reported from Iraq, Cameroon (Volcanic Area), India (Tamil Nadu), Egypt, Chile, Pakistan, Palestine and India (Maharastra), and less than the values of Jordan, India (Kerala), Malaysia (Cameroon Highlands), Malaysia and Nigeria. The activity concentration of ^{40}K shows higher than the most of the countries data reported in Table 2 except in Pakistan, Nigeria, Malaysia (Cameron Highland) and Jordan. Similarly, activity concentration of ^{232}Th lies above some of the countries except the data reported from India (Maharastra), Pakistan, Nigeria, and India (Kerala) and Malaysia. Such a heterogeneous behavior is usually observed following the differences in local geology of the soil in different regions in the world. The outdoor absorbed dose rate, outdoor annual effective dose, and ELCR values are reported in Table 3.

The population-weighted average outdoor absorbed dose rate in air in the world is 59 $nGyh^{-1}$ [6]. The average absorbed dose rate in air is quite similar to the world average absorbed dose rate except the sample 12. The excess lifetime cancer risk (ELCR) value is higher in sample 12 (Table 3). ELCR values of almost all the samples (except samples 6, 7, 10 & 12) are lower or very close to the recommended value of $< 0.29 \times 10^{-3}$ [6].

According to UNSCAER (2000) [6], the worldwide average outdoor annual effective dose due to external terrestrial radiation is 0.07 $mSvy^{-1}$. As shown in Fig. 5, most of the values of annual effective dose are less than 0.07 $mSvy^{-1}$ which indicates an insignificant hazards for human being.

Figure 6 shows the comparison of the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K among different places in Bangladesh including the soil samples from a few sea beaches [9, 10, 39–42]. It shows that the activity concentration of ^{226}Ra of the present study area is very similar to

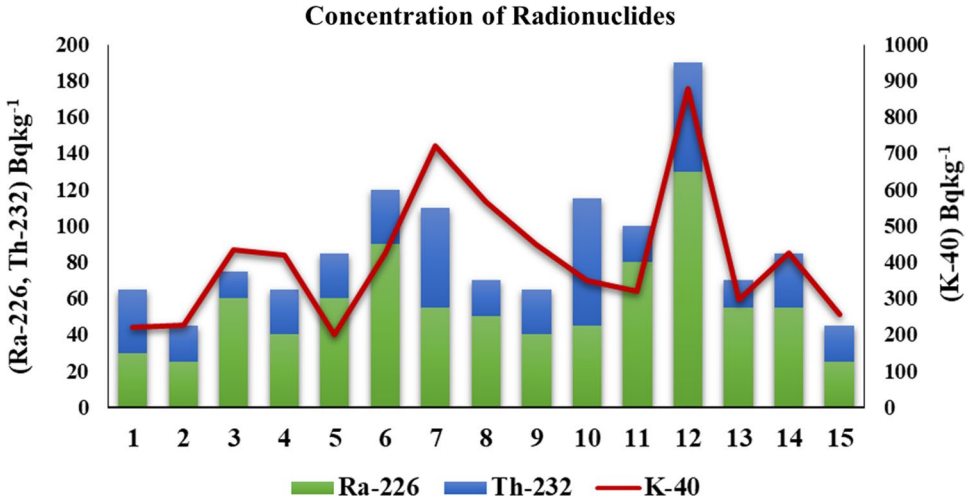

Fig. 4 Graphical representation of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K of sandy soil samples

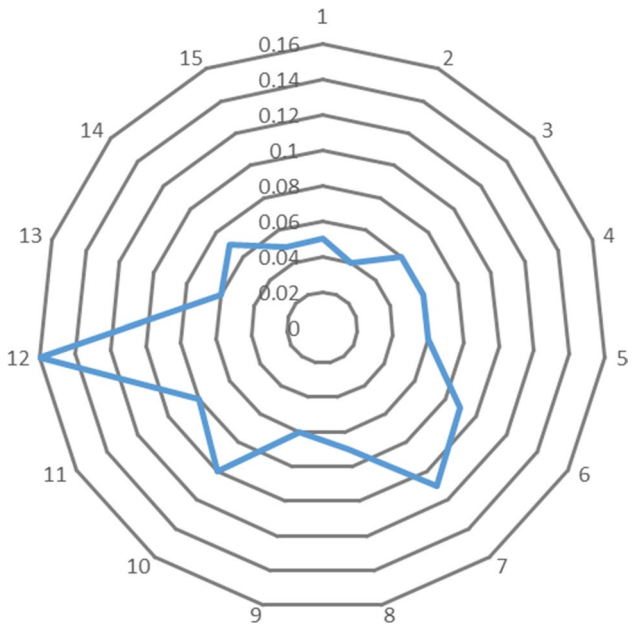

Fig. 5 Graphical representation of outdoor annual effective dose (mSv) due to soil samples

Table 2 Comparison of radionuclides concentrations in soil samples with other countries

District/region	Radioactivity concentration (Bqkg−1)		
	^{226}Ra	^{232}Th	^{40}K
Guliakhali Sea Beach, Sitakunda, Chittagong, Bangladesh (Present study)	56	31	412
Maharashtra, India [26]	44.97	59.70	217.51
Malaysia [27]	102.08	133.96	325.87
Kerala, India [28]	60.3	98.1	343.4
Cameron Highlands, Malaysia [29]	138.2	N/D	681.9
Iraq [30]	40	16	303
Volcanic area in Cameroon [31]	14	30	103
Tamil Nadu, India [32]	14.7	42.9	149.5
Jordan [33]	84	82	560
Chile [34]	15 to 30	22 to 30	411 to 611
North western desert, Egypt [35]	27.3	27.3	369.5
Chakwal, Pakistan [36]	34.27	51.59	606.42
Nigeria [37]	70.57	70.57	659.15
Palestine [38]	41.4	19.5	113.3

the other study areas except for the activity concentration of ^{226}Ra in Palaeo Beach, Teknaf which is very high [39]. The activity concentration of ^{232}Th also shows the same behavior. The activity concentration of ^{40}K seems quite different here. The activity concentration of ^{40}K in Savar, Dhaka and Habiganj areas is higher than the present study area, where the value is lower in Palaeo Brach, Teknaf than our study area. This happens because the soil characteristics and mineral components are differing from place to place. Although there are differences in the activities of these naturally occurring radionuclides, their values are generally below the safety limits provided by UNSCEAR [6] which reflects a general background radiation trend.

Conclusion

Assessment of the concentration of terrestrial radionuclides ^{226}Ra, ^{232}Th, and ^{40}K and their radiological implications associated with sandy soil samples collected from the Guliakhali sea beach, Sitakunda, Chattogram, Bangladesh was carried out in this study. It determines an overall mean value of 412 ± 19, 56 ± 5 and 31 ± 3 Bqkg^{-1} for ^{40}K, ^{226}Ra, and ^{232}Th respectively, and these values don't exceed (except ^{226}Ra) the corresponding world average values of 420, 32, and 45 Bqkg^{-1} for soil [6]. The distribution of activity concentration of these radionuclides

Table 3 Several radiological hazard parameters calculated from the measured radioactivity in the studied sandy soil samples

Sample ID	Outdoor absorbed dose rate, D_{out} ($nGyh^{-1}$)	Outdoor annual effective dose, E_{out} ($mSvy^{-1}$)	ELCR
1	44.4	0.05	0.19×10^{-3}
2	35.6	0.04	0.16×10^{-3}
3	52.3	0.06	0.23×10^{-3}
4	51.8	0.06	0.23×10^{-3}
5	51.2	0.06	0.23×10^{-3}
6	76.6	0.09	0.34×10^{-3}
7	89.5	0.11	0.40×10^{-3}
8	59.4	0.07	0.26×10^{-3}
9	52.5	0.06	0.23×10^{-3}
10	82.4	0.10	0.37×10^{-3}
11	61.8	0.08	0.27×10^{-3}
12	134.5	0.16	0.60×10^{-3}
13	45.9	0.06	0.20×10^{-3}
14	61.1	0.07	0.27×10^{-3}
15	36.3	0.05	0.16×10^{-3}
Min	35.6	0.04	0.16×10^{-3}
Max	134.5	0.16	0.60×10^{-3}
Mean	62.3	0.08	0.28×10^{-3}
UNSCEAR [6]	59	0.07	$<0.29\times10^{-3}$

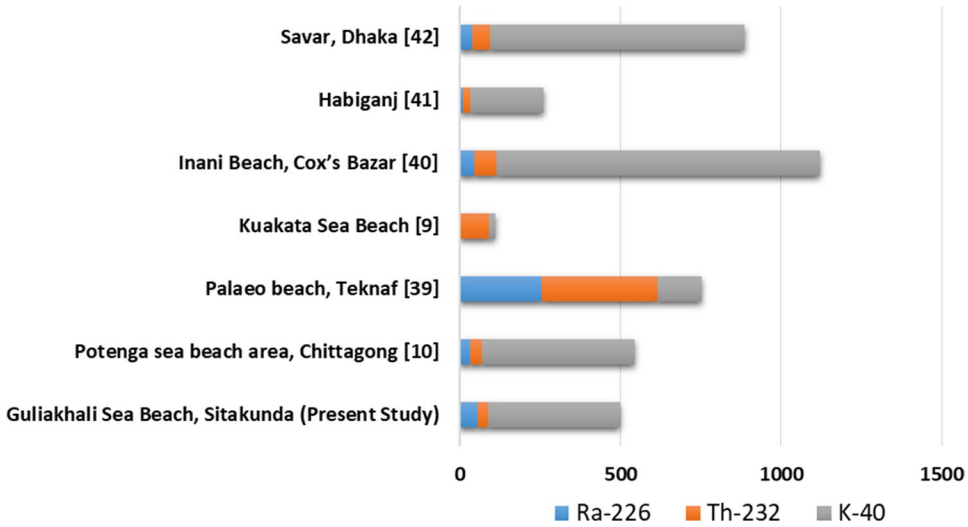

Fig. 6 Comparison of radioactivity levels in soil samples with other studies in Bangladesh

was not uniform with respect to the study location because of the geological character of the studied area. Although one sandy soil sample # 12 (22°36′50″ NL, 91°38′57″ EL) showed comparatively higher outdoor effective dose than the recommended safety limit, most of the values of annual effective dose are less than 0.07 $mSvy^{-1}$, which is the worldwide average outdoor annual effective dose [6]. Therefore, the radiation level of the sandy soil samples does not pose any health risk currently. The outcomes from this investigation may help to enrich the baseline radioactivity database in Bangladesh, and may contribute the radiological safety assessment for individuals living in the beachfront zones.

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Declarations

Conflict of interest The authors announce that they have no known contending monetary interests or individual connections that might

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References

1. Ionizing Radiation Levels and Effects (1972) A report of the United Nations Scientific Committee (UNSC) on the effects of atomic radiation to the general assembly, 1
2. Kolo MT, Khandaker MU, Shuaibu HK (2019) Natural radioactivity in soils around mega coal-fired cement factory in Nigeria and its implications on human health and environment. Arab J Geosci 12(15): 1–11. Doi: https://doi.org/10.1007/s12517-019-4607-6.
3. Abel-Ghany HA, El-Zakla T, Hassan AM (2009) Environmental radioactivity measurements of some Egyptian sand samples. Rom J Phys 54(1–2): 213–223
4. Shuaibu HK, Khandaker MU, Alrefae T, Bradley DA (2017) Assessment of natural radioactivity and gamma-ray dose in monazite rich black Sand Beach of Penang Island, Malaysia. Marine Pollut Bull 119(1): 423–428. Doi: https://doi.org/10.1016/j.marpolbul.2017.03.026
5. World Health Organization (1994) International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. General Safety Requirements (GSR) Part 3.
6. UNSCEAR (2000) Sources and effects of ionizing radiation. United Nations Scientific Committee on the effect of atomic radiation. Report to the General Assembly, with Scientific Annexes. United Nations, New York.
7. Ahmed MM, Das SK, Yeasmin S (2016) Natural Radioactivity and dose Assessment in Sand and Sediment Samples from Kuakata Beach, Bangladesh. J Bangladesh Acad Sci 40(1): 45–55
8. Al Amin M, Khandaker MU, Miah MH, Hossain S (2019) Radioactivity in coral skeletons and marine sediments collected from the St. Martin's Island of Bangladesh. J Radioanal Nuclear Chem 322(1): 157–163
9. Islam KMN, Paul D, Bhuiyan MMR, Akter A, Neher B, Islam SMA (2012) Study of environmental radiation on sand and soil samples from Kuakata sea beach of Patuakhali. J Environ Protect 3(9):1078–1084. Doi: https://doi.org/10.4236/jep.2012.39126
10. Yasmin S, Barua BS, Khandaker MU, Kamal M, Rashid MA, Sani SA, Bradley DA (2018) The presence of radioactive materials in soil, sand and sediment samples of Potenga sea beach area, Chittagong, Bangladesh: geological characteristics and environmental implication. Results Phys 1268–1274:8
11. Yeasmin S, Siraz MMM, Faisal A, Pervin S, Sultana MS (2015) Study of radioactivity in sand of a New Beach Zone at Cox's Bazar in the southern part of Bangladesh. In: International conference on physics sustainable development and technology (ICPSDT), Department of Physics, CUET, P-ID 91–96:46
12. Uddin MS, Barua BS, Shariff MA, Hasan MM, Rashid MA, Kamal M (2014) Investigation of elemental and radiological contamination of soils in two shipyards in Chittagong, Bangladesh. Radiochim Acta 102(8):741–749
13. Haydar MA, Hasan MM, Jahan I, Fatema K, Ali MI, Paul D, Khandaker MU (2021) The status of NORMs in natural environment adjacent to the Rooppur nuclear power plant of Bangladesh. Nucl Eng Technol. https://doi.org/10.1016/j.net.2021.06.025
14. Community Report (2012) Chittagong Zila, Population Census Wing, Bangladesh Bureau of Statistics (BBS). Retrieved 29 December 2015.
15. IAEA: International Atomic Energy Agency (1989) Measurement of radio-nuclides in food and the environment. Technical Report Series No. 295.
16. Asaduzzaman K, Mannan F, Khandaker, MU, Farook MS, Elkezza A, Amin YBM Abu Kassim HB (2015) Assessment of natural radioactivity levels and potential radiological risks of common building materials used in Bangladeshi dwellings. PLoS One 10(10):e0140667. Doi: https://doi.org/10.1371/journal.pone.0140667.
17. Sultana A, Siraz MM, Pervin S, Rahman AM, Das SK, Yeasmin S (2019) Assessment of radioactivity and radiological hazard of different food items collected from local market in Bangladesh. J Bangladesh Acad Sci 43(2):141–148. Doi: https://doi.org/10.3329/jbas.v43i2.45735.
18. IAEA (1987) Preparation and certification of IAEA gamma-ray spectrometry reference materials RGU-1, RGTh-1 and RGK-1 (IAEA-RL-148)
19. Khandaker MU, Heffny NA, DA, B. (2019) Elevated concentration of radioactive potassium in edible algae cultivated in Malaysian seas and estimation of ingestion dose to humans. Algal Res 1–8:38
20. Khandaker MU, Uwatse OB, Bin Shamsul Khairi KA, Faruque MRI, Bradley DA (2019) Terrestrial radionuclides in surface (dam) water and concomitant dose in metropolitan Kuala Lumpur. Radiation Protect Dosimetry 185(3):343–350
21. Amatullah S, Rahman R, Ferdous J, Siraz MMM, Khandaker MU, Mahal SF (2021) Assessment of radiometric standard and potential health risks from building materials used in Bangladeshi dwellings. Int J Environ Anal Chem, 1–13
22. Asaduzzaman K, Khandaker MU, Amin YM, Bradley DA (2016) Natural radioactivity levels and radiological assessment of decorative building materials in Bangladesh. Indoor Built Environ 25(3):541–550. Doi: https://doi.org/10.1177/1420326X14562048.
23. Siraz MMM, Pervin S, Banik S, Rahman AKMM, Rahman AFMM, Yeasmin S (2019) Estimation of radiation hazards from imported zirconium materials used in ceramic tiles industries in Bangladesh. Nuclear Sci Appl 28(1&2)
24. Debertin K, Helmer RG (1988) Coincidence-summing corrections. Gamma and X-ray spectrometry with Semiconductor detectors, Amsterdam, Netherlands: Elsevier Science Publishers BV, pp 258–269
25. Sarker MSD, Rahman R, Siraz MMM, Khandaker MU, Yeasmin S (2021) The presence of primordial radionuclides in powdered milk and estimation of the concomitant ingestion dose. Radiat Phys Chem 8:109597. https://doi.org/10.1016/j.radphyschem.2021.109597
26. Dhawal SJ, Phadatare MR, Thorat ND, Kulkarni GS, Pawar SH (2013) Natural radioactivity study in soil samples of South Konkan, Maharashtra, India. Radiation Protect Dosimetry 157(2):225–233. Doi:https://doi.org/10.1093/rpd/nct131.
27. Alzubaidi G, Hamid F, Abdul Rahman I (2016) Assessment of natural radioactivity levels and radiation hazards in agricultural and virgin soil in the state of Kedah, North of Malaysia. Sci World J 11:2016. https://doi.org/10.1155/2016/6178103
28. Venunathan N, Kaliprasad CS, Narayana Y (2016) Natural radioactivity in sediments and river bank soil of Kallada river of Kerala, South India and associated radiological risk. Radiation Protect Dosimetry 171(2):271–276. Doi: https://doi.org/10.1093/rpd/ncw073
29. Musa M, Hamzah Z, Saat A (2011) Measurement of natural radionuclides in the soil of Highlands agricultural farmland. In: 2011 3rd International symposium and exhibition in sustainable energy and environment (ISESEE), pp 172–176. IEEE. Doi:https://doi.org/10.1109/ISESEE.2011.5977083.
30. Taqi AH, Shaker AM, Battawy AA (2018). Natural radioactivity assessment in soil samples from Kirkuk city of Iraq using HPGe detector. Int J Radiat Res 16(4):455–463. Doi: https://doi.org/10.18869/acadpub.ijrr.16.4.455.
31. Ngachin M, Garavaglia M, Giovani C, Njock MK, Nourreddine A (2008) Radioactivity level and soil radon measurement of a

volcanic area in Cameroon. J Environ Radioactivity 99(7):1056–1060. Doi: https://doi.org/10.1016/j.jenvrad.2007.12.022.
32. Senthilkumar B, Dhavamani V, Ramkumar S, Philominathan P (2010) Measurement of gamma radiation levels in soil samples from Thanjavur using γ-ray spectrometry and estimation of population exposure. J Med Phys Assoc Med Phys India 35(1):48. Doi:https://doi.org/10.4103/0971-6203.55966.
33. Al-Jundi J, Al-Bataina BA, Abu-Rukah Y, Shehadeh HM (2003) Natural radioactivity concentrations in soil samples along the Amman Aqaba Highway, Jordan. Radiation Measure 36(1–6):555–560. Doi: https://doi.org/10.1016/S1350-4487(03)00202-6.
34. Correa R, Miranda PA, Ortiz-Ramirez P, Wachter J, Camilla S, Mera E, Piñones E (2018). Activity concentration of NORM and 137Cs radionuclide in soil samples from the Andes Cordillera at latitude 33° 56'South. J Phys Conf Ser 1043(1):012028. IOP Publishing. Doi:https://doi.org/10.1088/1742-6596/1043/1/012028.
35. Lasheen MA, Diab HM, Bashter II (2014) Study of natural radioactivity levels in soil samples using gamma-ray spectrometry. Arab J Nuclear Sci Appl 47(4):83–87
36. Rahman SU, Mehdi SA, Jahanzeb Q, Rafique M, Tareen ADK, Iqbal J (2018) Gamma rays measurements of naturally occurring radionuclides and resulting dose estimation in soil samples collected from district Chakwal. Pakistan J Rad Nucl 23–31:3. https://doi.org/10.18576/jrna/030103
37. Olise FS, Akinnagbe DM, Olasogba OS (2016) Radionuclides and radon levels in soil and ground water from solid minerals-hosted area, south-western Nigeria. Cogent Environ Sci 2(1):1142344. Doi: https://doi.org/10.1080/23311843.2016.1142344
38. Mohammad MK, Khali MT, Khrais FW (2014) Measurement of activity concentration levels of radionuclides in soil samples collected from Bethlehem Province, West Bank. Palestine Turk J Eng Environ Sci 113–125:38. https://doi.org/10.3906/muh-1303-8
39. Islam A, Sultana MS, Begum A, Yeasmin S (2013) Radioactivity level in soil of a palaeo beach in the south-eastern part of Bangladesh and evaluation of radiation hazard. Radiation Protection Dosimetry 157(2):255–264. Doi:https://doi.org/10.1093/rpd/nct135
40. Ahmed MM, Das SK, Haydar MA, Bhuiyan MMH, Ali MI, Paul D (2014) Study of natural radioactivity and radiological hazard of sand, sediment, and soil samples from Inani Beach, Cox's Bazar, Bangladesh. J Nuclear Part Phys 4(2):69–78
41. Ferdous J, Rahman MM, Rahman R, Hasan S, Ferdous N (2015) Radioactivity distributions in soils from Habiganj District, Bangladesh and their radiological implications. Malay J Soil Sci 59–71:19
42. Sarkar SC, Ali I, Paul D, Bhuiyan MR, Islam SMA (2011) Measurement of natural and artificial radioactivity in soil at some selected Thanas around the TRIGA Mark-II research reactor at AERE, Savar, Dhaka. J Environ Protect 2(10):1353. Doi: https://doi.org/10.4236/jep.2011.210156.