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Original Article

The status of NORMs in natural environment adjacent to the Rooppur nuclear power plant of Bangladesh

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ABSTRACT

The Rooppur Nuclear Power Plant (RNPP), the first nuclear power plant in Bangladesh with a capacity of 2.4 GWe, is under construction on the bank of the river Padma, at Rooppur in Bangladesh. Measurement of background radioactivity in the natural environment adjacent to RNPP finds great importance for future perspectives. Soil and sediment samples collected from upstream and downstream positions of the Padma River (adjacent to RNPP) were collected and analyzed by HPGe gamma-ray spectrometry for primordial radionuclides. The average activity concentrations (in $Bqkg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples were found to be 44.99 ± 3.89, 66.28 ± 6.55 and 553 ± 82.17 respectively. Respective values in sediment samples were found to be 44.59 ± 4.58, 67.64 ± 7.93, 782 ± 108. Relevant radiation hazard indices and dosimetric parameters were calculated and compared with the world average data recommended by US-EPA. Analytical results show non-negligible radiation hazards to the surrounding populace. Measured data will be useful to monitor any change of background radioactivity in the surrounding environment of RNPP following its operation for the generation of nuclear energy.

1. Introduction

Nowadays, the economic development of a nation is indirectly measured (and/or deeply entrenched) by the per capita use of electrical energy. Therefore, most of the nations look for a cost-effective and sustainable supply of electricity. Many developing countries, including Bangladesh are facing an increasing demand for energy to cope up with their on-going socio-economic development. To maintain sustainable financial growth, an arrangement of a long-term and stable energy generation pathway or source is required. From this viewpoint, a few years back, the government of Bangladesh took a firm decision to build or actualize (the fact that initially the decision was taken on several decades ago, in the early sixties-before the independence of Bangladesh, and acquired the necessary land at Rooppur by that government) the country's first nuclear power plant, called the Rooppur Nuclear Power Plant (RNPP) with a power generation capacity of 2.4 GWe from two units of VVER type reactor. The RNPP is now under construction on the bank of the river Padma, at Rooppur of Pabna District, in the northwest of the country. It has been expected that this plant will go into operation in 2023. Despite the huge benefit with the generation of electricity from a nuclear power plant, there remains a considerable impact on the environment which mainly comes from the nuclear fuel cycle (mining, enrichment, generation and geological disposal). A significant amount of radioactive waste is produced from the operation of a power plant, such as uranium mill tailings, spent (used) reactor fuel, etc., and it remains radioactive and dangerous to human health for thousands of years. Although, an operating nuclear power plant produces a negligible amount of radioactive gases, liquids and direct radiation (correspondingly an average dose of <0.01 mSv/year

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received by the general population from an operating nuclear power plant while it is ~3 mSv/year from background radiation), However, in the event of any natural (such as the 2011 Japanese tsunami that damaged the Fukushima-I nuclear power plant) or operational/technical (the 1979 Three Mile Island accident and 1986 Chernobyl disaster) failure, there is a 'catastrophic risk' potential. If so, the release and deposition of radioactive materials on the surrounding environment need to be assessed properly to understand the public exposure and possible remediation. In this regard, prior to commercial operation, knowledge of environmental radiation and background radioactivity has become an important issue for assessing the potential impact of the power plant on its surrounding environment. Before and after the construction of a nuclear power plant, it is important to track the radioactivity levels of environmental elements such as soil, sediment, and water body, and to determine the radiological doses at sites around a nuclear power plant. Regular monitoring is mandatory to evaluate the potential impacts on public health as well as environmental elements prior to the construction of a power plant and to ensure normality during commercial operations [1]. Such scrutinization is also practical for epidemiological studies, and to determine the potential modification in the environmental radioactivity due to nuclear, industrial, and other man-made activities [2].

The natural occurrence of primordial radionuclides ^{238}U, ^{232}Th, and ^{40}K in the earth's crust is the main root of background radiation in the environment. The ^{238}U and ^{232}Th day series consist of 15 and 12 progeny including the sub-series headed by ^{226}Ra and ^{228}Ra, respectively. Most of the short-lived progeny are either alpha or beta particle emitters accompanied by gamma rays. Additionally, among the naturally occurring potassium isotopes, ^{40}K is unstable and very long-lived and decays by the emission of a beta particle followed by the high energy 1460 keV gamma ray. All of these radionuclides are available in soils, sand, sediments, rocks, building materials, air, water, and foodstuff etc. Radionuclides in soil, sediment and water system may ultimately attain their way to humans via the food chain, and forms the major portion of radiation exposure to human beings via ingestion, inhalation, and also external exposure to gamma rays. Soil is the main environmental media that holds most of the lives on this planet. Determining soil radioactivity is important for understanding the changes within the natural background radiation [3], and to take necessary protective measures from unwanted radiation exposures.

The river Padma, one of the biggest water basins of Bangladesh flowing by the site of the mentioned Nuclear Power Plant (RNPP) at Rooppur, hence there is a possibility that the aquatic environment of the river will be contaminated somehow by the plant. To follow the extent of pollution, the baseline data should be established which may help in the future for an assessment of the influence of the plant-originated radio-toxins (if any) in the river environment. The knowledge of specific activities and distributions of ^{226}Ra, ^{232}Th, and ^{40}K in the collected soil and sediment samples from the Padma River region forms particular interest which provides valuable statistics on the background radioactivity in the nearby area of RNPP, and also for an estimation of the radiation exposures to the dwelling populace at that area. It is therefore expected that the results obtained in this study will be required as regulatory prerequisites in the future for the operation of RNPP.

2. Materials and methods

2.1. Study area

The study area was situated on the bank of the Padma River, in the district of Pabna, approximately 170 km northwest of Bangladesh's capital city of Dhaka. The site coordinates are located between the northern longitudes of 24°06′20.63 ′and 24°02′19.45′ and between the eastern longitudes of 89°01′38.78′ and 89°02′26.13'. Soil and sediment samples were collected from the selected locations (shown in Fig. 1) around the bank of the Padma River.

2.2. Sample collection and preparation

A total of 20 samples (10 soil and 10 sediment samples) were collected from the upstream and downstream positions of the Padma river adjacent to the Rooppur Nuclear Power Plant (RNPP) at Rooppur, Iswardi, Pabna, maintaining a distance of about 1 km from each other. The soil samples were collected at a depth of 5–10 cm concerning the surface. Approximately 0.5–1.0 kg of solid (i.e. soil and sediment) samples were collected from each selected location and packaged in identified plastic packages correctly and for processing and characterization, all the samples were transported to the Health Physics and Radioactive Waste Management Unite (HPRWMU), INST, AERE, Savar, Dhaka.

2.3. Processing of solid samples

The collected soil and sediment samples were taken to the mentioned laboratory for the preparation of samples in a good manner. After cleaning and drying the samples in the sun, all the samples were crushed into fine powder with the help of a grinder. To get homogenized samples, all the crashed samples were passed through a mesh screen of 400 μm. The studied experimental samples were then dried for around 24 h at 110 °C to remove residual moisture completely. The weighted (using an electronic balance) powdered samples were then transferred to sealable radon-impermeable airtight cylindrical plastic containers (7 cm height and 5.5 cm in diameter) marked with identification parameters. All the samples were stored to maintain the radioactive secular equilibrium for more than four weeks between ^{226}Ra and its daughter products to be achieved prior to gamma spectroscopy [4]. Fig. 2 shows a schematic block diagram for the whole process, i.e., from sampling to the report of prevailing concentrations of radionuclides of interest in the surrounding environment of RNPP.

2.4. Data collection and analysis technique

The detection and measurement of the concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the collected samples were carried out using gamma ray spectrometry setup with vertical, coaxial, cylindrical Canberra high-purity germanium (HPGe) detector having relative efficiency of 20% [5]. The energy resolution of the selected p-type HPGe detector was determined by 1.8 keV Full Width at Half Maximum (FWHM) for the 1332 keV peak of ^{60}Co gamma-ray line. There was a shielding arrangement to cut down the background radiation in the laboratory room and the samples were counted for 10,000 s placing on the upper part of the detector maintaining the necessary parameter like resolution, peak to Compton ratio, etc minimizing the detectable activity of the detector. The Genie-2000 spectra analysis software was used to analyze the gamma-rays emitted from all the studied samples accurately. The environmental background data was acquired with the help of an identical empty plastic container (without any sample) in the mentioned laboratory for obtaining net counts for corresponding radionuclides (by deducting from sample counts) before the measurements of experimental samples. The energy regions selected for the relative nuclides were estimated by using its progeny of ^{214}Pb (295 keV, 352 keV) and ^{214}Bi (609 keV, 1120 keV, 1764 keV) for ^{226}Ra; ^{208}Tl (583 keV, 2614 keV) and ^{228}Ac (911 keV, 969 keV) for ^{228}Th; and finally the singly occurring 1460 keV and 661.66 keV for ^{40}K and ^{137}Cs respectively.

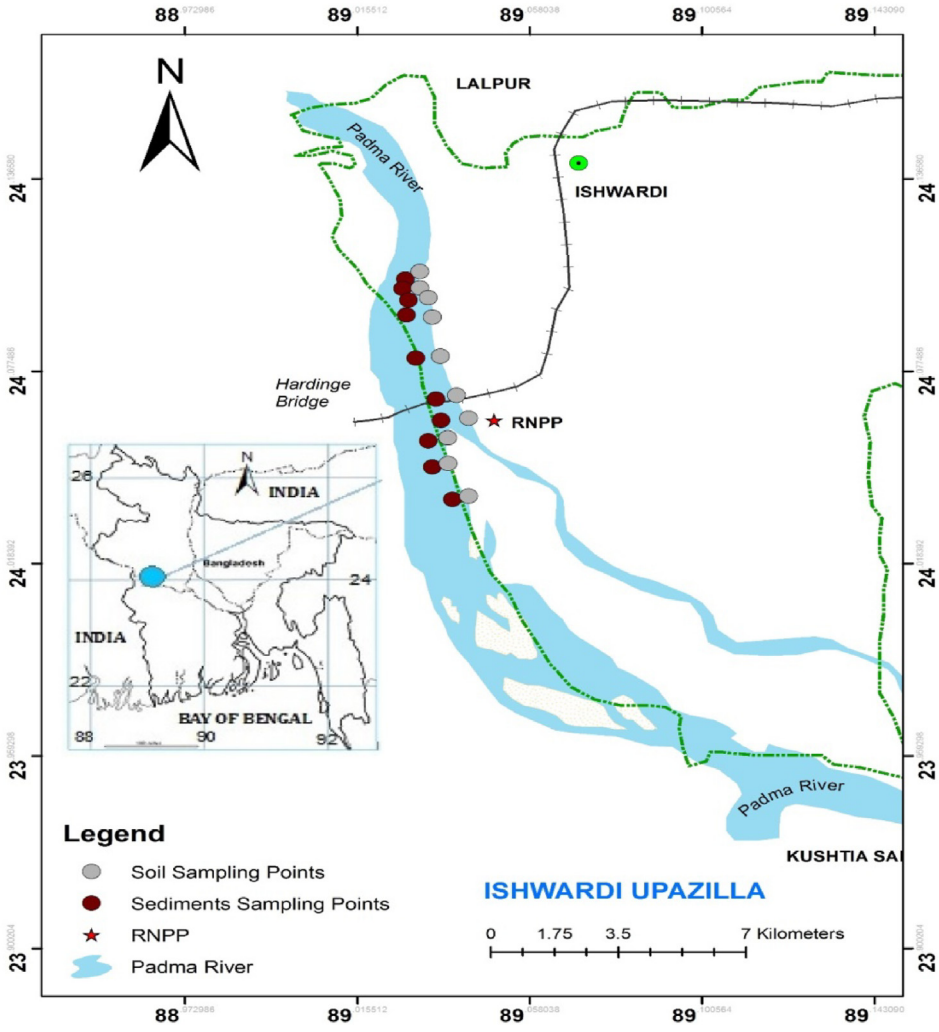

Fig. 1. Sample's location in Map of Rooppur, Ishwardi Upazilla, Pabna, Bangladesh.

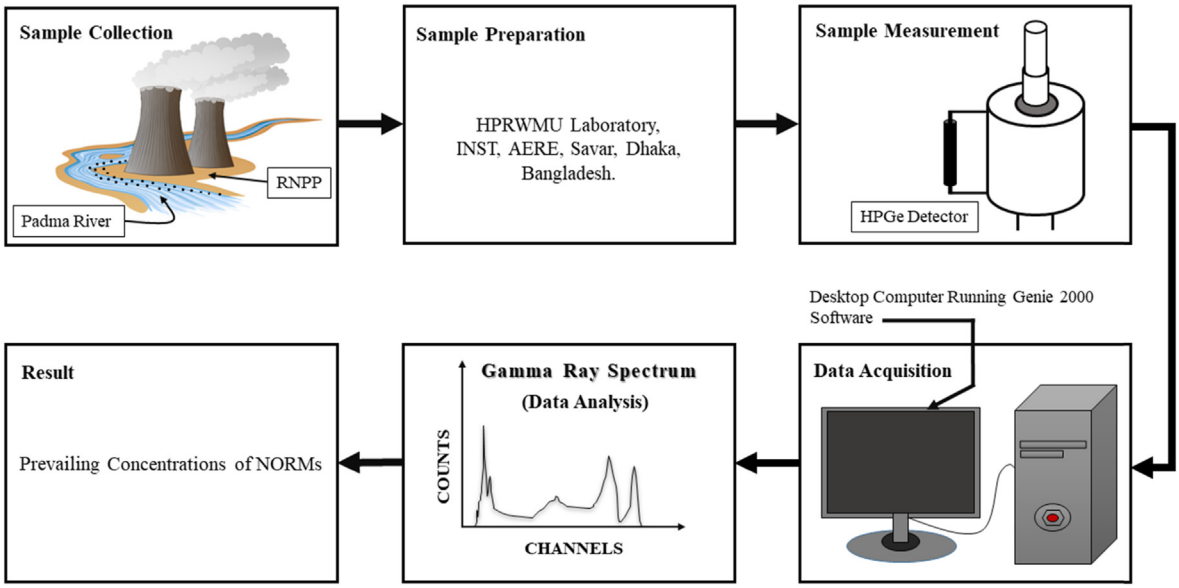

Fig. 2. Schematic block diagram for the whole process (from sampling to the report of obtained data).

3. Calculations of activity concentrations

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides (in $Bqkg^{-1}$) in all the investigated samples were calculated using Eq. (1) and expressed as [6,7]:

$$A = \frac{cps}{E \times I \times W} \tag{1}$$

where, A represents the activity concentrations of the studied samples in $Bqkg^{-1}$, cps is the net counts per second (cps for the sample - cps for the background) for each sample, E is the photopeak efficiency of the detector at respective gamma-ray energy, I is emission probability of the corresponding gamma-ray energy, and W is the net weight of the sample in gram. The expanded uncertainty of the measurements was expressed in terms of combined standard uncertainty considering all known uncertainty components at coverage factor $k = 1$ b y using Eq. (2) [8].

$$\text{Combined Standard Uncertainty} = \sqrt{\left(\frac{u(N)}{N}\right)^2 + \left(\frac{u(T)}{T}\right)^2 + \left(\frac{u(I_\gamma)}{I_\gamma}\right)^2 + \left(\frac{u(m)}{m}\right)^2 + \left(\frac{u(E)}{E}\right)^2} \tag{2}$$

where, N, T, I_γ, m and E are the sample counts, counting time, gamma-ray emission probability, sample weight, and counting efficiency, respectively and u(N),$u(T)$,$u(I_\gamma)$, $u(m)$ and $u(E)$ are their respective uncertainties. The repeatability of the reported results (i.e., the reported concentrations of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides) were ensured by triplicate measurements of each sample under the same measurement condition and counting time. It has been found a close value (within the error bar) to one-another measurements, and this fact confirm the accuracy of our measurement system.

3.1. Estimation of radiation hazard indicators

3.1.1. Radium equivalent activity (Ra_{eq})

To represent the activities of different radionuclides for the experimental samples collectively, the radium equivalent activity (Ra_{eq}) has been calculated by Eq. (3) according to the concept of Beretka and Matthew [9].

$$Ra_{eq}\left(Bqkg^{-1}\right) = A_{Ra} + 1.43A_{Th} + 0.007A_K \tag{3}$$

where, A_{Ra}, A_{Th}, and A_K represent the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in $Bqkg^{-1}$, respectively in the selected samples.

3.1.2. External absorbed gamma dose rates ($\boldsymbol{D_R}$)

The D_R parameter bears a significant contribution to assess the pathway of radiation hazards to the biological environment. The absorbed dose rates were calculated due to gamma rays at 1 m above the ground via Eq. (4) [8]:

$$D_R\left(nGyh^{-1}\right) = 0.4551A_{Ra} + 0.5835A_{Th} + 0.0429A_K \tag{4}$$

3.1.3. Annual effective dose equivalent ($\boldsymbol{E_{aed}}$)

External annual effective dose equivalent is a measure of exposure risk associated with absorbed dose received by an individual. It was calculated via Eq. (5) with the help of a conversion factor 0.7 $SvGy^{-1}$ which transforms absorbed dose rate in the air to an effective dose in tissue [10], and the outdoor occupancy factor of 0.2 with a conversion factor 10^{-6} from nano-to-milli by considering that general person spent 20% on an average of their outing time [11]:

$$E_{aed}\left(mSvyr^{-1}\right) = D_R \times 24 \times 365 \times 0.2 \times 0.7 \times 10^{-6} \tag{5}$$

3.1.4. External hazard index (H_{ex})

The external hazard index due to the contribution of various radionuclides helps to comprehend the radiological parameter of the studied samples. To neglect the radiation hazards, the estimated value of H_{ex} using Eq. (6) should be always less than one [12]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{6}$$

3.1.5. Internal hazard index (H_{in})

Due to the inhalation of ^{222}Rn and its progenies (short-lived), respiratory organs can be exposed seriously which is controlled by a single quantity radiological hazard parameter known as hazard index (internal) and can be estimated by using Eq. (7) [13].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{7}$$

According to UNSCEAR (2000), unity is the precautionary protection limit for the above parameter.

3.1.6. Excess lifetime cancer risk (ELCR)

The percentage of a life-threatening disease called cancer is increasing day by day due to various reasons and radiation hazard is one of them. That is why we were interested to assess the excess lifetime cancer risk (ELCR) of the experimental samples to represent the likelihood of cancer occurrence from radiation exposure. The ELCR was calculated using Eq. (8) considering 70 years as the average span of life to low-level radiation of continuous exposure [14]:

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \tag{8}$$

Where AEDE is the annual effective dose equivalent, DL is the average span of life (70 years) for the people of Bangladesh, and RF defined as a risk factor assumed to be 0.05 Sv^{-1} recommended by ICRP for stochastic effects in any given population in this study [15].

4. Results and discussion

Table 1 shows that the estimated activity concentrations for both the soil and sediment samples lie in the range of 20.90 ± 2.99

Table 1
Activity concentration ($Bqkg^{-1}$) of ^{226}R, ^{232}Th, ^{40}K, and Radium equivalent (Ra_{eq}) activity in the collected soil and sediment from the selected locations.

Sample name	Sample ID	Location		Activity concentration			Ra_{eq}
		Longitude	Latitude	**^{226}Ra**	**^{232}Th**	**^{40}K**	
Soil	PSo-1	89° 01′ 33.37″ E	24° 06′ 27.83″ N	43.44 ± 4.23	53.67 ± 7.10	716 ± 95.07	175
	PSo-2	89° 01′ 43.87″ E	24° 06′ 10.15″ N	39.67 ± 3.86	63.03 ± 7.18	529 ± 84.60	170
	PSo-3	89° 01′ 44.33″ E	24° 05′ 57.22″ N	127 ± 6.75	206 ± 10.70	653 ± 96.43	472
	PSo-4	89° 01′ 47.06″ E	24° 05′ 40.90″ N	31.32 ± 3.26	50.91 ± 5.57	473 ± 74.64	140
	PSo-5	89° 01′ 57.04″ E	24° 04′ 53.16″ N	36.94 ± 3.46	60.68 ± 6.39	411 ± 73.03	155
	PSo-6	89° 02′ 06.12″ E	24° 04′ 07.81″ N	52.77 ± 4.26	78.85 ± 7.52	617 ± 84.73	212
	PSo-7	89° 02′ 11.18″ E	24° 03′ 44.17″ N	20.90 ± 2.99	22.87 ± 4.89	537 ± 81.43	94.94
	PSo-8	89° 02′ 16.26″ E	24° 03′ 24.87″ N	27.01 ± 2.95	33.73 ± 4.76	481 ± 70.19	112
	PSo-9	89° 02′ 16.52″ E	24° 02′ 56.48″ N	33.72 ± 3.50	47.41 ± 5.71	546 ± 80.62	143
	PSo-10	89° 02′ 28.93″ E	24° 02′ 19.45″ N	36.42 ± 3.59	45.50 ± 5.66	569 ± 80.93	145
Average (Range)				44.99 ± 3.89 (20.9 ± 2.9 −127.8 ± 6.8)	66.28 ± 6.55 (22.87 ± 4.89 −206.16 ± 10.70)	553 ± 82.17 (411 ± 73.03 −716 ± 95.07)	182 (94.94 −472)
Sediment	PSe-1	89°01′38.78″ E	24°06′20.63″ N	54.07 ± 5.14	71.76 ± 8.92	943 ± 129	229
	PSe-2	89°01′36.38″ E	24° 06′ 10.15″ N	38.92 ± 4.17	53.02 ± 6.78	675 ± 98.50	166
	PSe-3	89° 01′ 41.42″ E	24° 05′ 57.22″ N	39.80 ± 3.85	66.08 ± 6.56	641 ± 86.10	183
	PSe-4	89° 01′ 39.46″ E	24° 05′ 40.90″ N	60.91 ± 4.85	87.11 ± 7.72	564 ± 92.91	228
	PSe-5	89° 01′ 47.80″ E	24° 04′ 53.16″ N	22.06 ± 2.95	39.47 ± 5.81	490 ± 77.27	116
	PSe-6	89°02′ 05.82″ E	24° 04′ 07.81″ N	47.83 ± 5.30	76.55 ± 9.47	1107 ± 131	242
	PSe-7	89° 02′ 10.16″ E	24° 03′ 44.17″ N	23.41 ± 3.07	20.96 ± 4.98	583 ± 81.04	98
	PSe-8	89° 02′ 14.43″ E	24° 03′ 24.87″ N	43.30 ± 3.68	88.60 ± 7.23	453 ± 73.47	204
	PSe-9	89° 02′ 18.28″ E	24° 02′ 58.17″ N	52.90 ± 6.10	91.12 ± 10.84	1219 ± 153	276
	PSe-10	89° 02′ 26.13″ E	24° 02′ 19.45″ N	62.70 ± 6.66	81.68 ± 10.70	1147 ± 157	267
Average (Range)				44.59 ± 4.58 (22.06 ± 2.95 −62.70 ± 6.66)	67.64 ± 7.93 (20.96 ± 4.98 −91.12 ± 10.84)	782 ± 108 (453 ± 73.47 −1219 ± 153)	201 (98 −276)
World AVG [11].				35	30	400	370

ND=Not Detectable.

to 127 ± 6.75 and 22.06 ± 2.95 to 62.70 ± 6.66 $Bqkg^{-1}$ for ^{226}Ra; 22.87 ± 4.89 to 206 ± 10.70 and 20.96 ± 4.98 to 91.12 ± 10.84 $Bqkg^{-1}$ for ^{232}Th; 411 ± 73.03 to 716 ± 95.07 and 453 ± 73.47 to 1219 ± 153 $Bqkg^{-1}$ for ^{40}K, respectively. For all the soil and sediment samples, the activity shows an overall order of ^{226}Ra<^{232}Th < ^{40}K. All these values show significantly higher than the world average values (35, 30, and 400 $Bqkg^{-1}$) except for PSe-5, PSe-7, PSo-4, PSo-8, PSo-9 (^{226}Ra) and PSe-7, PSo-7 (^{232}Th). The activity concentration of ^{232}Th was pointed out to be higher than the ^{226}Ra in almost all the soil and sediment samples. This is because the radium is more susceptible to solubility.

In the collected soil and sediment samples, low values of ^{226}Ra are for the absence of uranium-rich minerals such as apatite, zircon, etc. It is also noticeable that an elevated concentration of ^{40}K is observed in all the soil and sediment samples as compared to UNSCEAR (2000). This could follow farmers' agricultural practices where they use a large quantity of chemical fertilizer (NPK, TSP and SSP) to improve crop production. As agricultural fertilizes contain various elements like uranium, thorium, and potassium in trace amounts, they can increase the concentrations of radionuclides in the soil [16] as well as sediments. The calculated Ra_{eq} value for the soil and sediment samples show an average of 201 and 182 $Bqkg^{-1}$ which lie below the global average of 370 $Bqkg^{-1}$ for a material to be used in construction or other similar purposes [11]. This indicates that the radiological hazards associated with the studied environmental samples are insignificant.

4.1. Activity ratio of the samples

The activity ratio between two radionuclides of interest provides knowledge on how the radionuclides are correlated. The dominating radionuclide can be identified from the activity ratio.

4.1.1. Correlation between ^{226}Ra and ^{232}Th

Correlation is a statistical tool used to calculate and to describe the strength and direction of the relationship between two variables and a correlation coefficient makes a bridge to understand the degree (strength) of the relationship between two variables. Table 2 shows the activity ratio among ^{226}Ra, ^{232}Th, and ^{40}K radionuclides of sediment samples collected from the Padma River and soil

Table 2
Activity ratio of soil and sediment samples collected from selected areas.

Sample ID	Activity ratio of $^{226}Ra/^{232}Th$	Activity ratio of $^{226}Ra/^{40}K$	Activity ratio of $^{232}Th/^{40}K$
PSo-1	0.809	0.061	0.075
PSo-1	0.629	0.075	0.119
PSo-3	0.620	0.196	0.316
PSo-4	0.615	0.066	0.108
PSo-5	0.609	0.090	0.147
PSo-6	0.669	0.086	0.128
PSo-7	0.914	0.039	0.043
PSo-8	0.801	0.056	0.070
PSo-9	0.711	0.062	0.087
PSo-10	0.800	0.064	0.080
PSe-1	0.754	0.057	0.076
PSe-2	0.734	0.058	0.078
PSe-3	0.602	0.062	0.103
PSe-4	0.699	0.108	0.154
PSe-5	0.559	0.045	0.081
PSe-6	0.625	0.043	0.069
PSe-7	1.117	0.040	0.036
PSe-8	0.489	0.096	0.195
PSe-9	0.581	0.043	0.075
PSe-10	0.768	0.055	0.071

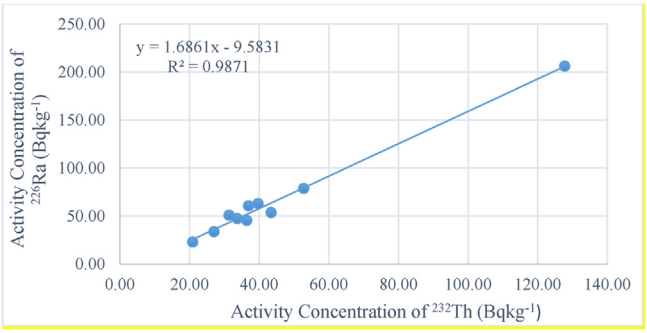

Fig. 3. Correlation between activity concentration of ^{226}Ra and ^{232}Th of all soil samples of the adjacent area of the Padma River.

samples from the adjacent area of the Padma River. From this table, it is clear that ^{226}Ra and ^{232}Th are positively correlated (i.e., these are from the same/similar sources), while the very low ratio of $^{226}Ra/^{40}K$ and $^{232}Th/^{40}K$ indicate the differences in their origins.

More precisely, the correlations between the activities of ^{226}Ra and ^{232}Th, as shown in Figs. 3 and 4 are roughly linear in soil and sediment samples, with correlation coefficients of 0.98 and 0.74, respectively. It is imitated by these relations that the soil samples come from the same source type, whereas the differences in origin are seen by the sediment samples. During weathering or following

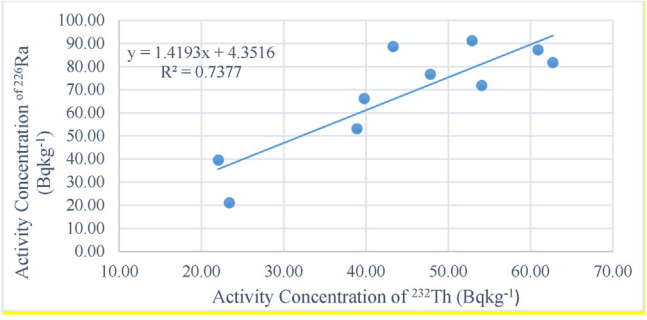

Fig. 4. Correlation between activity concentration of ^{226}Ra and ^{232}Th of all sediment samples of the Padma River.

the dynamics of sediment samples through water current, this indicates a significant fractionation.

Table 3 shows the calculated hazard indices (H_{ex}, H_{in}), radiation dose (D_R, E_{aed}), and radiation risk (ELCR) due to the soil and sediment samples. All calculated H_{ex} and H_{in} values are lower than unity except PSo-3 which confirms that there are no significant radiological hazards. The recorded averages for D_R ($nGyh^{-1}$), E_{aed} ($mSvyr^{-1}$) and ELCR are 84.07, 0.10, and 0.36 $Bqkg^{-1}$ for soil samples; and 94.32, 0.12 and 0.40 for sediment samples, respectively. All the values of D_R (except PSo-7, PSo-8, PSe-5 and PSe-7) exceed the world average value of 59 ($nGyh^{-1}$) whereas all the values of E_{aed} are lower than world average value 0.46 ($mSvyr^{-1}$). Most of the calculated values of ELCR (except PSo-4, PSo-7, PSo-8, PSo-9, PSo-10, PSe-5 and PSe-7) are recorded somewhat higher than that of the world average value 0.29×10^{-3} [11].

4.2. Radiological hazard assessment

In Table 4, we have compared our findings with other reported data in some published works of literature worldwide. We see that all the reported data of our present study are in the range of world average values ranging 17–60, 11–64, and 140–850 $Bqkg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K respectively except for the activity concentrations of ^{232}Th in soil and sediment samples [11]. The lowest (highest) activity concentrations in sediment samples are 6.43(94.39), 200.21(1002) $Bqkg^{-1}$ for ^{226}Ra and ^{40}K respectively whereas 6 (162.8) $Bqkg^{-1}$ represents the lowest (highest) activity concentration for ^{232}Th in soil samples reported by V. Ramasamy et al., 2011, Sabina Yasmin et al., 2018; A. El-Gamal et al., 2007, Md. Ibrahim Khalil et al., 2016; and Sroor et al., 2001 and J. Beretka et al., 1985 in a sequence [[9,18–22].

5. Conclusion

Concentrations of primordial radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were determined in soil and sediment samples collected from the adjacent area of the Rooppur Nuclear Power Plant at Rooppur, Pabna district of Bangladesh. No artificial radionuclides were found in any of the samples studied. Measured data of radionuclides of interest in the studied samples show higher values than the world average values. The calculated radium equivalent and hazard indices (both internal and external) are lower than the world

Table 3
Calculated radiological parameters due to the ^{226}Ra, ^{232}Th, and ^{40}K in the studied soil and sediment samples.

Sample ID	H_{ex}	H_{in}	D_R	E_{aed}	ELCR× 10^{-3}
PSo-1	0.47	0.59	82.57	0.10	0.35
PSo-2	0.46	0.57	78.63	0.10	0.35
PSo-3	1.28	1.62	210.98	0.26	0.91
PSo-4	0.38	0.46	65.10	0.08	0.28
PSo-5	0.42	0.52	71.00	0.09	0.32
PSo-6	0.58	0.72	97.93	0.12	0.42
PSo-7	0.26	0.31	46.06	0.06	0.21
PSo-8	0.30	0.38	53.08	0.07	0.25
PSo-9	0.39	0.48	67.16	0.08	0.28
PSo-10	0.39	0.49	68.21	0.08	0.28
Average (range)	0.49 (0.26–1.28)	0.62 (0.31–1.62)	84.07 (46.06–210.98)	0.10 (0.06–0.26)	0.36 (0.21–0.91)
PSe-1	0.62	0.77	107.95	0.13	0.46
PSe-2	0.45	0.56	78.39	0.10	0.35
PSe-3	0.50	0.60	85.24	0.10	0.35
PSe-4	0.62	0.78	104.48	0.13	0.46
PSe-5	0.31	0.37	54.62	0.07	0.25
PSe-6	0.66	0.78	114.85	0.14	0.49
PSe-7	0.27	0.33	47.98	0.06	0.21
PSe-8	0.56	0.67	92.56	0.11	0.39
PSe-9	0.75	0.90	130.68	0.16	0.56
PSe-10	0.72	0.90	126.49	0.16	0.56
Average (range)	0.55 (0.27–0.75)	0.67 (0.33–0.90)	94.32 (47.98–130.68)	0.12 (0.06–0.16)	0.40 (0.21–0.56)
World Average [11,17]	1	1	59	0.46	0.29

Table 4
Comparison of present results with similar literature data from other published related literature.

Sample name	Location	Activity Concentration			Reference
		^{226}Ra	^{232}Th	^{40}K	
Soil	Australia	62.9	162.8	403.3	[9]
	China	44	47	593.1	[23]
	Egypt	13	6	433	[22]
	Pakistan	46.5	60.8	698.6	[24]
	India (South-west)	50 ± 12	58 ± 10	380 ± 61	[25]
	Nigeria	7.41 ± 0.44	16.27 ± 0.84	196.11 ± 9.08	[26]
	Dinajpur, Bangladesh	23.54 ± 2.6	52.10 ± 4.73	603.17 ± 66.40	[6]
	Potenga sea beach, Bangladesh	65.90 ± 5.74	83.17 ± 4.83	946.9 ± 5.9	[19]
	Southern Part of Bangladesh	34.8 ± 3.8	48.9 ± 2.8	719 ± 59	[27]
	RNPP Site, Pabna, Bangladesh	30.85	40.88	390.10	[2]
	RNPP site, Bangladesh	44.99 ± 3.89	66.28 ± 6.55	553.59 ± 82.17	Present Study
Sediment	Egypt, Nile river	16.30	12.94	200.21	[20]
	India, Ponnaiyar river	6.43 ± 2.71	52.76 ± 5.40	395.67 ± 27.93	[18]
	Brahmaputra (Jamuna) river, Bangladesh	60 ± 2	113 ± 5	1002 ± 43	[21]
	Potenga sea beach, Bangladesh	94.39 ± 8.05	121.9 ± 6.2	498.0 ± 7.4	[19]
	RNPP site, Padma River	44.59 ± 4.58	67.64 ± 7.93	782.68 ± 108.11	Present Study
World Standard value (range and average)		Range:17–60 Average:35	Range:11–64 Average:30	Range:140–850 Average:400	[11]

average value, indicating the non-hazardous nature of the samples. On the other hand, the gamma-absorbed dose rate and outdoor annual effective dose were found to be relatively higher than the world average. The calculated concentrations of terrestrial radionuclides in the soil and sediment samples studied typically display equivalent or slightly higher results compared to similar studies conducted in other countries. The high correlation coefficient between ^{226}Ra and ^{232}Th in soil samples reflects the same source of origin. The data found in this study are the latest so it can be used as baseline data for the adjacent area of RNPP. It is expected that the obtained data will be useful to monitor any change of background radioactivity in the surrounding environment of RNPP following the operation of the nuclear power plant in the future.

CRediT authorship contribution statement

Md Abu Haydar: Conceptualization, Formal analysis. **Md Mehade Hasan:** Writing – original draft, Data curation. **Imrose Jahan:** Resources, Visualization. **Kanij Fatema:** Resources, Software. **Md Idris Ali:** Supervision. **Debasish Paul:** Supervision. **Mayeen Uddin Khandaker:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] T.-L. Tsai, C.-C. Lin, T.-W. Wang, T.-C. Chu, Radioactivity concentrations and dose assessment for soil samples around nuclear power plant IV in Taiwan, J. Radiol. Prot. Off. J. Soc. Radiol. Prot. 28 (2008) 347–360, https://doi.org/10.1088/0952-4746/28/3/005.

[2] J. Ferdous, A. Begum, A. Islam, Radioactivity of soil at proposed Rooppur nuclear power plant site in Bangladesh TT -, Int-J-Radiat-Res. 13 (2015) 135–142, https://doi.org/10.7508/ijrr.2015.02.003.

[3] A. Kurnaz, B. Küçükömeroğlu, R. Keser, N.T. Okumusoglu, F. Korkmaz, G. Karahan, U. Çevik, Determination of radioactivity levels and hazards of soil and sediment samples in Fırtına Valley (Rize, Turkey), Appl. Radiat. Isot. 65 (2007) 1281–1289, https://doi.org/10.1016/j.apradiso.2007.06.001.

[4] K. Asaduzzaman, M.U. Khandaker, Y.M. Amin, D.A. Bradley, R.H. Mahat, R.M. Nor, Soil-to-root vegetable transfer factors for 226Ra, 232Th, 40K, and 88Y in Malaysia, J. Environ. Radioact. 135 (2014) 120–127, https://doi.org/10.1016/j.jenvrad.2014.04.009.

[5] M.A.R. Iyengar, The national distribution of radiation, in: The Environment Behaviour of Radium in: Technical Report Series N.310, International Atomic Energy Agency, Vienna, 1990. Vienna.

[6] S.M.A. Islam, M. Mehade Hasan, M.I. Ali, D. Paul, M.A. Haydar, Measurement of natural radioactivity in coal, soil and water samples collected from barapukuria coal mine in dinajpur district of Bangladesh, J. Nucl. Part. Phys. 3 (2013) 63–71, https://doi.org/10.5923/j.jnpp.20130304.03.

[7] Y.M. Amin, M.U. Khandaker, A.K.S. Shyen, R.H. Mahat, R.M. Nor, D.A. Bradley, Radionuclide emissions from a coal-fired power plant, Appl. Radiat. Isot. 80 (2013) 109–116, https://doi.org/10.1016/j.apradiso.2013.06.014.

[8] K. Asaduzzaman, M.U. Khandaker, Y.M. Amin, D.A. Bradley, Natural radioactivity levels and radiological assessment of decorative building materials in Bangladesh, Indoor Built Environ. 25 (2014) 541–550, https://doi.org/10.1177/1420326X14562048.

[9] J. Beretka, P.J. Matthew, Natural radioactivity of Australian building materials, industrial wastes and by-products, Health Phys. 48 (1985) 87–95, https://doi.org/10.1097/00004032-198501000-00007.

[10] Sources UNSCEAR, Effects and Risk of Ionization Radiation, Annex A: Exposure from Natural Sources, Report to General Assembly, UN, United Nations Scientific Committee on the Effects of Atomic Radiation, New York, 1993, 1993.

[11] UNSCEAR, Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes, 2000.

[12] M.R. Karim, M.U. Khandaker, K. Asaduzzaman, H.A. Razak, S.B. Yusoff, Radiological risks assessment of building materials ingredients: palm oil clinker and fuel ash, Indoor Built Environ. 28 (2018) 479–491, https://doi.org/10.1177/1420326X18776705.

[13] L. Xinwei, Z. Xiaolan, Measurement of natural radioactivity in sand samples collected from the Baoji Weihe Sands Park, China, Environ. Geol. 50 (2006) 977–982, https://doi.org/10.1007/s00254-006-0266-5.

[14] K. Asaduzzaman, F. Mannan, M.U. Khandaker, M.S. Farook, A. Elkezza, Y.B.M. Amin, S. Sharma, H. Bin Abu Kassim, Assessment of natural radioactivity levels and potential radiological risks of common building materials used in Bangladeshi dwellings, PloS One 10 (2015), e0140667, https://doi.org/10.1371/journal.pone.0140667.

[15] M. Hasan, A. Hossain Chaity, A. Haydar, I. Ali, M.U. Khandaker, Elevated concentrations of terrestrial radionuclides in sand: an essential raw material used in Bangladeshi dwellings, Indoor Built Environ. (2020), 1420326X20924835, https://doi.org/10.1177/1420326X20924835.

[16] National Council on Radiation Protection and Measurements, Knovel (Firm), A Handbook of radioactivity measurements procedures with nuclear data for some biomedically important radionuclides, reevaluated between August 1983 and April 1984, NCRP Rep. No. 58 (1985).

[17] UNSCEAR, Sources and Effects of Ionizing Radiation, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, 2008.

[18] V. Ramasamy, G. Suresh, V. Meenakshisundaram, V. Ponnusamy, Horizontal and vertical characterization of radionuclides and minerals in river sediments, Appl. Radiat. Isot. Incl. Data, Instrum. Methods Use Agric. Ind. Med. 69 (2011) 184–195, https://doi.org/10.1016/j.apradiso.2010.07.020.

[19] S. Yasmin, B.S. Barua, M.U. Khandaker, M. Kamal, M. Abdur Rashid, S.F. Abdul Sani, H. Ahmed, B. Nikouravan, D.A. Bradley, 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 8 (2018) 1268–1274, https://doi.org/10.1016/j.rinp.2018.02.013.

[20] A. El-Gamal, S. Nasr, A. El-Taher, Study of the spatial distribution of natural radioactivity in the upper Egypt Nile River sediments, Radiat, Measure 42 (2007) 457–465, https://doi.org/10.1016/j.radmeas.2007.02.054.

[21] M. Khalil, R. Majumder, M. Kabir, F. Deeba, M. Khan, M. Ali, D. Paul, M. Haydar, S. Islam, Assessment of natural radioactivity levels and identification of minerals in Brahmaputra (Jamuna) river sand and sediment, Bangladesh, Radiat. Protect. Environ. 39 (2016) 204–211, https://doi.org/10.4103/0972-0464.199980.

[22] A. Sroor, S.M. El-Bahi, F. Ahmed, A.S. Abdel-Haleem, Natural radioactivity and radon exhalation rate of soil in southern Egypt, Appl. Radiat. Isot. 55 (2001) 873–879, https://doi.org/10.1016/S0969-8043(01)00123-3.

[23] P. Ziqiang, Y. Yin, G. Mingqiang, Natural radiation and radioactivity in China, Radiat. Protect. Dosim. 24 (1988) 29–38, https://doi.org/10.1093/oxfordjournals.rpd.a080236.

[24] S.M.M.M. Tufail, N. Ahmad, N.M. Mirza, Activity con-centration in building Materials,Centre for nuclear studies, in: Rep. No. CNS-25, Isalamabad Pakistan, slamabad,Pakistan, 1992.

[25] M.U. Khandaker, P.J. Jojo, H.A. Kassim, Y.M. Amin, Radiometric analysis of construction materials using HPGe gamma-ray spectrometry, Radiat. Protect. Dosim. 152 (2012) 33–37, https://doi.org/10.1093/rpd/ncs145.

[26] M.T. Kolo, M.U. Khandaker, H.K. Shuaibu, Natural radioactivity in soils around mega coal-fired cement factory in Nigeria and its implications on human health and environment, Arab. J. Geosci. 12 (2019) 481, https://doi.org/10.1007/s12517-019-4607-6.

[27] R. Khan, M.S. Parvez, Y.N. Jolly, M.A. Haydar, M.F. Alam, M.A. Khatun, M.M.R. Sarker, M.A. Habib, U. Tamim, S. Das, S. Sultana, M.A. Islam, K. Naher, D. Paul, S. Akter, M.H.R. Khan, F. Nahid, R. Huque, M. Rajib, S.M. Hossain, Elemental abundances, natural radioactivity and physicochemical records of a southern part of Bangladesh: implication for assessing the environmental geochemistry, Environ. Nanotechnology, Monit. Manag. 12 (2019) 100225, https://doi.org/10.1016/j.enmm.2019.100225.