Primordial radionuclides in the dust samples from the educational institutions of central Bangladesh: radiological risk assessment

Md. Joynal Abedin a,b, Rahat Khan b,*

a Centre for Higher Studies and Research, Bangladesh University of Professionals (BUP), Mirpur Cantonment, Mirpur, Dhaka 1216, Bangladesh
b Institute of Nuclear Science & Technology, Bangladesh Atomic Energy Commission, Savar, Dhaka 1349, Bangladesh

A R T I C L E   I N F O
Keywords:
Classroom-dust samples
Primordial radionuclides ($^{226}$Ra, $^{232}$Th, $^{40}$K)
Educational institutions
Environmental distributions
Radiological health hazards

A B S T R A C T
For the first time, this study presents the radio-activity concentrations of primordial radionuclides in a suite of classroom-dusts collected from 23 schools in central part of Bangladesh. Bulk elemental compositions from instrumental neutron activation analysis (INAA) were transformed into accompanied radio-activity contents (Bq.kg$^{-1}$). Mean activity contents of $^{226}$Ra, $^{232}$Th, & $^{40}$K in dust samples were 86.0, 43.4, and 448 Bq.kg$^{-1}$, respectively, which were comparatively elevated relative to the relevant world average value. Higher NORMs abundances were due to the surface soil weathering and aerodynamic fractionations. Estimation of typical radiological-risk indices demonstrates human health risks. Bearing in mind that the greater susceptibility of school-going juveniles & children to the ionizing-radiations & the entering of NORMs-comprising dust-particle into human lungs, calculated radiological indices merely represent the least potential risk. However, in actual cases, $\alpha$-particles from the $^{238}$U and $^{232}$Th-decay series can create significant radiation-damage to the respiratory-system.

1. Introduction

Naturally occurring primordial radioactive nuclides in ambient environment are of great concern for their hazardous impacts on human-health through ionizing radiations. Various types of physiological problems, e.g., lung cancer, renal failure, kidney dysfunction, and bone deformities may be caused by exposure to NORMs (Majlis et al., 2022; Islam et al., 2022; Habib et al., 2019a, 2019b). NORMs distributions in different environmental constituents (e.g., dust, sediment, soil, water) mostly depend on climatic conditions, local geology, & weathering processes (Khan et al., 2022a, 2022b; Alonso-Hernández et al., 2018; Alam et al., 1999). NORMs’ occurrence in soil and/or sediment is mostly correlated with external exposure to radiation if the inhalation of gaseous radon is overlooked. Though the NORMs’ impacts by water having various exposure routes, the impacts seem trivial due to the very low abundances of NORMs in the natural resources of water (Habib and Khan 2021; Arogunjo et al., 2009). Moreover, like water, radioactivity abundance in dust cannot be disregarded. Additionally, like soil or sediment, exposures of radiation through dust-NORMs are not limited merely through external-route (ignoring the inhalation of radon). Rather dust can have the probability of entering in lungs through the inhalation route (Apeagyei et al., 2011; Ahmad and MatiullahKhatibeh, 1997) along with its radionuclides.

In urban areas, dust particles normally originating from surface soil through several weathering progressions, e.g., collective actions of heat and turbulent airflow, rain, water logging, etc. Other than the anthropogenic processes, natural processes, e.g., construction works, industrial activities, vehicular transportation, etc. play significant role in the formation of dust and determine the compositions of elements in the generated dust (Addo et al., 2020). Mostly dust particle generated from surface geo-materials (e.g., soil or/and sand), which coherently carry NORMs in it’s compositions, can eventually cause radiological risks. Dust, particularly road-dusts have been studied by numerous researchers (e.g., Ahmed et al., 2007; Ghavanati et al., 2018; Abbasi et al., 2013; Mohtaderi et al., 2019; Kormoker et al., 2021; Kabir et al., 2021a, 2021b) for potentially toxic heavy metal’s abundances. However, research on NORMs concentrations in dust samples have hardly been conducted (Addo et al., 2020; Abedin and Khan, 2022; Mahdi et al., 2015). Moreover, classroom-dusts collected from different educational institutions have rarely been conducted, even for elements having potential toxicity. Bulk chemical compositions of indoor-dusts can also be correlated to the room’s air-quality (Praveena et al., 2015; Soltani et al., 2015) that may
also cause health risks. Furthermore, children & juveniles are relatively more vulnerable to environmental heavy metal(oids) (Habib et al., 2020; Jannat et al., 2022; Mehtaderi et al., 2019; Islam et al., 2020a, 2020b; Medunic et al., 2016; Kumar et al., 2022, 2021a, 2021b; Ahmed et al., 2021; Hossain et al., 2022a, 2022b; Rahman et al., 2022; Anik et al., 2022). Thus, studies on NORM’s occurrence in the dust of classrooms are of utter importance. But the literature studies on the NORM’s abundance in classroom dust are too scarce to obtain.

Measurements of NORMs abundances have normally been carried out by HPGe-detector which requires 100–250g solid samples. Moreover, samples required at least 28 days to attain the secular equilibrium (between short-lived daughter & long-lived parent) followed by a long time γ-ray-counting (25,000–50,000s) (Bramha et al., 2018; Ehsan et al., 2019). If the mass of samples is lower, it requires a longer counting time. Additionally, higher uncertainty is also introduced from background radiations in measured data. However, collected mass of dusts from the surface of the classroom benches are typically low (~20–25g), it does not permit for determining the primordial radionuclide’s activity conventionally (described before). So, a passive way has been adopted to measure NORMs in the dust samples to overcome this problem. In this study, a precise and highly accurate, non-destructive and primary nuclear permit for determining the primordial radionuclide.

2.3. Instrumental neutron activation analysis

2.3.1. Sample preparation

Approximately 60 mg of each powdered dust sample was weighed in 1 × 1 cm² polyethylene bag, double-packed & heat-sealed. NIST-1633b (coal-fly-ash: standard reference material) was utilized as standard (multi-elemental comparator) whereas reference materials (provided by IAEA) RM-SI-1 and RM-Soil-7 were utilized as monitoring samples for maintaining the quality of measured data. Along with the studied samples, standard, and control samples, Al-0.1% Au-foil (530RA) was utilized for monitoring the neutron-flux.

2.3.2. Sample irradiation

All collected samples, reference materials, & comparator were put in the irradiation-tube and were irradiated by thermal neutrons (flux: 1.54 × 10¹⁵ cm⁻² s⁻¹) at 500 kW for 2 h in a 3 MW TRIGA Mark-II research reactor of Bangladesh Atomic Energy Commission (Savar, Dhaka). Following the same experimental process, procedure-blank was also irradiated and necessary corrections were made accordingly (Begum et al., 2021a). Three Au-Al-monitor foils were individually irradiated inserting them at the differential positions (top, middle, & bottom) of the sample stack to monitor neutron flux gradient (Tamim et al., 2016).

2.3.3. Gamma-ray counting, spectrum acquisition, and data calculation

Irradiated samples with systematic decaying were undertaken through γ-ray counting using HPGe-detector (CANBERRA, 40% rel. efficiency, & 1.8 keV resolution) attached with digital γ-spectrometer (ORTEC, DSPEC Jr™) (Khan et al., 2020, 2019b, 2019c). First gamma-ray counting was done in 40 min (after ~two days of decay) and 2nd gamma-ray counting was done for three (3) hours (after ~seven days of decay). From the first gamma-ray counting (L1), K & U were identified while Th was identified from the 2nd gamma-ray counting (L2). Genie-2000 (Canberra) and Hypermet PC (version-5.12) were utilized to acquisition of data and analysis of gamma-photo-peak analysis, respectively (Khan et al., 2017, 2018).

2.3.4. Data quality and radioactivity estimation

The accuracy and precision of analytical data (Table 2) were checked by triplicate analysis of SI-1 & Soil-7. In view of the ranges of analytical uncertainties, determined results of elemental concentrations in control samples were concomitant with the IAEA-certificate values. Precision (RSDs, %) of this work for the determined elemental concentrations in Soil-7 & SI-1 ranged from 4.5 to 8.3%. Following are the standard Eqs. (1), (2), and (3) by which elemental concentrations of K (in %), U (in μg/g), & Th (in μg/g) in classroom-dusts were transformed to the accompanied radioactivity abundances (Bq/kg) (Bajoga et al., 2019; IAEA--TEC-DOC, 2003):

\[ \frac{Bq}{kg} = \frac{313 \times 10^{-12} K + 12.35 \times 10^{-12} Ra + 4.06 \times 10^{-12} Th}{\mu g/g} \]

2.4. Radiological indices

2.4.1. Radium equivalent activity (RaEQ)

Naturally, radioactivity concentrations of NORMs in the surrounding environmental materials like soil, sediments, or dust are not even. “Radium equivalent activity (RaEQ)” index is applied to eliminate the non-uniform activity of radionuclides (Ravisankar et al., 2015). This can be computed by employing the subsequent Eq. (4):

Collected all classroom-dust samples were then dried by oven (for 24 h at ~45–50 °C) and were ground to obtain homogeneous sample.

2.2. Sample collection and processing

In Bangladesh, for about 1.5 years (17 March 2020 to 12 September 2021) educational institutions were closed due to the COVID-19 pandemic. During this period, classroom furniture (table, chair, benches) was covered by a layer of dust-particles. Dust samples deposited on the table’s and benches’ surface were collected with the aid of a plastic brush in zip-lock polythene bags. From 3 to 5 different classrooms of a single institution dust samples were collected and were mixed together for having a representative composite dust sample. From twenty-three (23) different schools, representative dust samples were collected (Table 1). Collected mass of each dust sample ranged from 15 to 25 g.
Figure 1. Sampling locations (educational institutions) for the dust samples from central Bangladesh.
Table 1. Samples information of the studied area (Mirpur, Bangladesh) along with their ancillary data.

| Sample ID | School Name | Year of Establishment | GPS data | Latitude  | Longitude |
|-----------|-------------|-----------------------|----------|-----------|-----------|
| D-1       | Monipur High School & College (Be-2) | 1969 | 23°47'49.5"N 90°23'02.9"E |
| D-2       | Rotary School and College | 1976 | 23°48'01.5"N 90°22'51.3"E |
| D-3       | Glory School and College-1 | 2006 | 23°47'04.2"N 90°22'28.6"E |
| D-4       | Banafat Adibi School Green Heart College | 1976 | 23°48'19.7"N 90°22'33.8"E |
| D-5       | Mirpur Girls Ideal College | 1978 | 23°48'26.5"N 90°22'17.0"E |
| D-6       | Mirpur Adarsho High School | 1966 | 23°48'23.0"N 90°22'14.8"E |
| D-7       | Senpara Porbota Govt Primary School | 1943 | 23°48'27.9"N 90°22'13.0"E |
| D-8       | Monipur High School and College (Girls) | 1969 | 23°48'00.8"N 90°21'49.1"E |
| D-9       | Monipur Govt Primary School | 1966 | 23°48'00.9"N 90°21'55.6"E |
| D-10      | Sheikh Fazlul Hossain Mohila College | 1980 | 23°48'16.2"N 90°21'35.1"E |
| D-11      | Mirpur College | 1970 | 23°48'14.9"N 90°21'39.1"E |
| D-12      | National Bangla High School | 1966 | 23°48'18.5"N 90°21'44.1"E |
| D-13      | Paikpara Govt Primary School | 1986 | 23°47'36.8"N 90°21'29.9"E |
| D-14      | Wak-Up High School | 2000 | 23°47'23.6"N 90°21'11.3"E |
| D-15      | Wak Up Govt Primary School | 1989 | 23°47'24.6"N 90°21'10.2"E |
| D-16      | Islamia High School | 1995 | 23°48'45.5"N 90°21'33.8"E |
| D-17      | Candour International School | 1999 | 23°49'30.5"N 90°21'54.3"E |
| D-18      | SOS Hermann Gmeiner School and College | 1986 | 23°48'17.7"N 90°22'38.6"E |
| D-19      | Cosmo School | 2013 | 23°49'21.3"N 90°21'52.9"E |
| D-20      | Heed International School | 2003 | 23°49'03.3"N 90°21'57.9"E |
| D-21      | Shahred Abu Taleb High School | 1975 | 23°48'35.8"N 90°22'09.8"E |
| D-22      | Glory School and College-2 | 2006 | 23°48'10.6"N 90°22'42.0"E |
| D-23      | Mirpur English version School and College | 2013 | 23°48'24.6"N 90°22'28.8"E |

\[ Ra_{eq} = \left( \frac{A_{232Th}}{370} + \frac{A_{226Ra}}{259} + \frac{A_{40K}}{4810} \right) \times 370 \]  

where, the radioactivity concentrations of 232Th, 226Ra, & 40K are represented by \( A_{232Th} \), \( A_{226Ra} \), and \( A_{40K} \), respectively. For potential radiological safety appraisal, the maximum permissible value of \( Ra_{eq} \) (Isinkaye and Emelue, 2015) were fixed to 370 Bq kg\(^{-1}\).

2.4.2. External & internal hazard indices (\( H_{ex} \) & \( H_{in} \))

In view to determine the externally exposed radiation (ionizing) doses to specific persons from classroom-dusts, external hazard index (\( H_{ex} \)) can be computed by Eq. (5). Moreover, the internal hazard index (\( H_{in} \)) is utilized to assess the radiological hazards posed due to radon & its progenies which can be calculated by using Eq. (6) (Begum et al., 2021b).

\[ H_{ex} = \frac{A_{222Rn}}{370 \text{ Bq kg}^{-1}} + \frac{A_{226Ra}}{259 \text{ Bq kg}^{-1}} + \frac{A_{232Th}}{4810 \text{ Bq kg}^{-1}} \]
studied after the year of 2000 (Table 4). However, the median

\[ H_n = \frac{A_{40K}}{185 \text{ Bq kg}^{-1}} + \frac{A_{232Th}}{259 \text{ Bq kg}^{-1}} + \frac{A_{226Ra}}{4810 \text{ Bq kg}^{-1}} \]  

(6)

In which \( A_{40K} \), \( A_{232Th} \), and \( A_{226Ra} \) denote the radioactivity abundances of radionuclides \( ^{232}\text{Th}, ^{226}\text{Ra}, \) and \( ^{40}\text{K} \), respectively. According to UNSCEAR, (2000), \( H_{40K} \) and \( H_{40K} \) values should be < 1 for keeping the radiation generated hazard trivial.

### 2.4.3. Absorbed gamma dose rate (D)

Naturally occurring radioactive nuclides have contributions to the D-values relies upon the radioactivity abundances of NORMs. Moreover, there is an instantaneous association among terrestrial gamma-radiation and activity concentrations of NORMs that once the activity concentration is known later the affiliated exposure dose rate above 1 m air of the ground surface can be computed by using Eq. (7) (Isinkaye and Emelue, 2015; Ravisanakar et al., 2015).

\[ D (\text{nGy h}^{-1}) = 0.462 A_{40K} + 0.604 A_{232Th} + 0.0417 A_{226Ra} \]  

(7)

Here, the factors demonstrated by UNSCEAR, (2000) for converting the activity contents of \( ^{232}\text{Th} \) (\( A_{232Th} \)), \( ^{226}\text{Ra} \) (\( A_{226Ra} \)), and \( ^{40}\text{K} \) (\( A_{40K} \)) into the dose rate (nGy h\(^{-1}\)) per Bq kg\(^{-1}\) are 0.604, 0.462, & 0.0417, respectively.

### 2.4.4. Annual effective dose rate (AEDE)

AEDE can be computed from the D-value by employing the converting factor (CF) of 0.7 Sv GY, stay time in the classrooms is 20% of 8760 h.y \(^{-1}\) (occupancy factor: OF). As per described above, the AEDE was measured by Eq. (8) (UNSCEAR, 2000).

\[ \text{AEDE} = D (\text{nGy h}^{-1}) \times 8760 \text{h y}^{-1} \times 0.2 \times 0.7 \times 10^{-6} \]  

(8)

### 2.4.5. Gamma representative level index (I\(_G\))

\( I_G \) can be employed to appraise the natural \( \gamma \)-radiation risk levels from classroom-dusts involved with gamma-emitters. \( I_G \) correlated with annual dose-criterion because of excessive \( \gamma \)-radiation by superficial materials and served as like a screening instrument for the sake of determining materials that can cause health concerns. Following Kolo et al. (2015), \( I_G \) can be estimated by Eq. (9):

\[ I_G = \frac{A_{40K}}{150} + \frac{A_{232Th}}{100} + \frac{A_{226Ra}}{1500} \]  

(9)

### 2.4.6. Excess lifetime cancer risk (ELCR)

Potential carcinogenic health hazards are represented by measuring the probability of cancer manifestation of individuals for a certain lifetime from slope factors (SF) and estimated exposures. ELCR is calculated by employing Eq. (10) (Khandaker et al., 2018).

\[ \text{ELCR} = \text{AEDE} \times A_T \times R_f \]  

(10)

Here, AEDE represents annual effective dose equivalent, \( A_T \) denotes the average lifetime (70 years) & \( R_f \) denotes the cancer-risk-factor (SV\(^{-1}\); ICRP, 1990) which is considered to be 0.5 \( \times \) 10\(^{-4}\) for the mass public exposures.

### 3. Results and discussion

#### 3.1. NORMs' concentrations and distributions

Elemental concentrations of K (in %), \( U \) (μg g\(^{-1}\)), & \( \text{Th} \) (μg g\(^{-1}\)) in analyzed classroom-dusts along with the estimated radioactivity abundances (in Bq kg\(^{-1}\)) are showed in Table 3. The average\(_{n=23}\) activity contents of \( ^{232}\text{Th}, ^{226}\text{Ra}, \) & \( ^{40}\text{K} \) in the classroom-dusts were respectively 43.4, 86.0, and 488 Bq kg\(^{-1}\), which are relatively higher in comparison to corresponding world average values (\( ^{232}\text{Th}: 30; ^{226}\text{Ra}: 35; ^{40}\text{K}: 400 \) Bq kg\(^{-1}\); UNSCEAR, 2000). This world average values were considered from the studies carried out before the year of 2000 while this study has complied the data of \( ^{232}\text{Th}, ^{226}\text{Ra}, \) and \( ^{40}\text{K} \) for surface soils, that were
Table 3. Elemental abundances, their conversion to radioactivity concentrations, and affiliated ratios in the dust samples collected from the classrooms of schools (Mirpur, central Bangladesh) along with their descriptive statistics.

|       | K [%] | Th [μg/g] | U [μg/g] | Th/U | 226Ra [Bq.kg⁻¹] | 232Th [Bq.kg⁻¹] | 40K [Bq.kg⁻¹] | 232Th/40K | 226Ra/40K | 232Th/226Ra |
|-------|-------|-----------|----------|------|-----------------|-----------------|----------------|-------------|------------|-------------|
| D-1   | 1.42  | 0.04      | 11.8     | 0.1  | 4.37            | 0.17            | 54.0           | 2.1         | 48.1       | 0.5         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-2   | 1.76  | 0.04      | 12.5     | 0.1  | 13.4            | 0.37            | 165.3          | 4.6         | 50.6       | 0.5         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-3   | 1.33  | 0.04      | 7.17     | 0.1  | 8.08            | 0.26            | 99.8           | 3.2         | 29.1       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-4   | 1.93  | 0.05      | 17.6     | 0.1  | 7.15            | 0.23            | 88.3           | 2.9         | 71.5       | 0.6         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-5   | 1.88  | 0.04      | 14.7     | 0.1  | 4.12            | 0.16            | 109.4          | 4.4         | 32.2       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-6   | 1.81  | 0.05      | 7.93     | 0.1  | 7.25            | 0.24            | 109.4          | 4.4         | 32.2       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-7   | 1.88  | 0.05      | 11.7     | 0.1  | 8.66            | 0.28            | 109.4          | 4.4         | 32.2       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-8   | 1.67  | 0.04      | 10.9     | 0.1  | 1.98            | 0.11            | 244.4          | 1.3         | 44.3       | 0.5         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-9   | 1.74  | 0.05      | 10.7     | 0.1  | 4.69            | 0.21            | 109.4          | 4.4         | 32.2       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-10  | 1.83  | 0.04      | 11.9     | 0.1  | 2.36            | 0.11            | 109.4          | 4.4         | 32.2       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-11  | 1.37  | 0.04      | 6.48     | 0.07 | 6.74            | 0.23            | 83.2           | 2.9         | 26.3       | 0.3         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-12  | 1.79  | 0.05      | 4.56     | 0.07 | 7.23            | 0.24            | 83.2           | 2.9         | 26.3       | 0.3         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-13  | 1.23  | 0.04      | 9.31     | 0.1  | 15.6            | 0.43            | 193.0          | 5.3         | 37.8       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-14  | 1.28  | 0.04      | 10.3     | 0.1  | 7.21            | 0.23            | 91.2           | 3.1         | 32.2       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-15  | 1.34  | 0.04      | 8.94     | 0.1  | 7.38            | 0.25            | 138.6          | 4.0         | 22.1       | 0.3         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-16  | 0.72  | 0.03      | 5.44     | 0.07 | 11.2            | 0.32            | 105.0          | 3.0         | 37.8       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-17  | 1.42  | 0.04      | 11.3     | 0.1  | 6.44            | 0.18            | 105.0          | 3.0         | 37.8       | 0.4         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-18  | 0.86  | 0.05      | 14.6     | 0.1  | 8.06            | 0.28            | 99.6           | 3.5         | 59.1       | 0.6         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-19  | 1.36  | 0.06      | 15.2     | 0.1  | 16.0            | 0.44            | 197.3          | 5.4         | 61.8       | 0.6         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-20  | 1.41  | 0.06      | 15.7     | 0.1  | 5.00            | 0.20            | 61.7           | 2.5         | 63.9       | 0.6         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-21  | 1.34  | 0.05      | 9.51     | 0.12 | 1.02            | 0.07            | 12.6           | 0.9         | 38.6       | 0.5         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-22  | 0.42  | 0.04      | 3.94     | 0.07 | 6.57            | 0.26            | 81.1           | 3.2         | 16.0       | 0.3         |
|       |       |           |          |      |                 |                 |                |             |            |             |
| D-23  | 1.14  | 0.06      | 13.8     | 0.1  | 1.16            | 0.09            | 197.3          | 7.1         | 603        | 0.221       |
|       |       |           |          |      |                 |                 |                |             |            |             |

Mean (n = 23) | 1.43 | 0.04 | 10.70 | 0.1  | 6.96            | 0.23            | 86.0           | 2.6         | 43.4       | 0.5         |

SD (1σ) | 0.39 | 3.67 | 4.08 | 2.88 | 50.4           | 14.9            | 12.2           | 0.039 | 0.175 |

RSD (%) | 27.3 | 34.3 | 58.7 | 108.2 | 34.3           | 38.0            | 78.2           | 108.2 |

Median | 1.41 | 10.91 | 7.15 | 1.44 | 88.3           | 44.3            | 440            | 0.098 | 0.160 |

Min. | 0.42 | 3.94 | 1.02 | 0.49 | 12.6           | 16.0            | 133            | 0.033 | 0.030 |

Max. | 1.93 | 17.6 | 16.0 | 11.9 | 197.3          | 71.5            | 603            | 0.221 | 0.613 |
Radioactivity concentrations of this study are compared with those of various locations worldwide.

### Table 4. Radioactivity concentrations of this study compared with those of various locations worldwide.

| Location                  | $^{226}$Ra | $^{232}$Th | $^{40}$K | References/Comments |
|---------------------------|------------|------------|---------|---------------------|
| **Max.**                  | 86.0       | 43.4       | 448     | This study          |
| **SD (1σ)**               | 50.4       | 14.9       | 122     |                     |
| **RSD (%)**               | 58.7       | 34.3       | 27.3    |                     |
| **Median**                | 88.3       | 44.3       | 440     |                     |
| **Min.**                  | 12.6       | 16.0       | 133     |                     |
| **Surface soils of Bangladesh** |           |            |         |                     |
| Pabna, Bangladesh         | 13.4       | 15.6       | 202     | Ehsan et al. (2019) |
| Cox’s Bazar, Bangladesh   | 44.4       | 69.8       | 1007    | Ahmad and MatriullahKhatibeh (1997) |
| Gazipur, Bangladesh       | 66.7       | 101.6      | 425     | Islam et al. (2014) |
| Kutia, Bangladesh         | 6.3        | 6.6        | 225     | Ehsan et al. (2019) |
| Natore, Bangladesh        | 16.5       | 7.0        | 143     | Ehsan et al. (2019) |
| Sylhet, Bangladesh        | 55.3       | 125.3      | 498     | Miah et al. (2012)  |
| Hobiganj, Bangladesh      | 11.1       | 22.0       | 228     | Ferdous et al. (2015) |
| Chattogram, Bangladesh    | 35.9       | 65.5       | 272     | Chowdhury et al. (1999) |
| Chattogram, Bangladesh    | 21         | 40.0       | 449     | Mojumder et al. (2020) |
| Rajbari, Bangladesh       | 29         | 50.9       | 535     | Khatun et al. (2013) |
| Chattogram, Bangladesh    | 61         | 79.7       | 857     | Alam et al. (2013)  |
| Rampal, Bangladesh        | 34.8       | 48.9       | 719     | Khan et al. (2019b) |
| Rangpur, Bangladesh       | 87         | 140        | 1844    | Hamid et al. (2002) |
| **Median (n = 13)**       | 34.8       | 50.9       | 449     |                     |

### Surface soils of the Indian subcontinent

| Location                  | $^{226}$Ra | $^{232}$Th | $^{40}$K | References/Comments |
|---------------------------|------------|------------|---------|---------------------|
| **Max.**                  | 37.0       | 69.4       | 396     | Mishra (2004)       |
| **SD (1σ)**               | 28.6       | 51.0       | 570     | Badhan and Mehra (2012) |
| **RSD (%)**               | 55.3       | 55.3       | 729     | Babai et al. (2012)  |
| **Median**                | 17.0       | 15.2       | 143     |                     |
| Nasik, India              | 45         | 59.7       | 218     | Dhawal et al. (2013) |
| Kolaghat, India           | 61.7       | 622.4      | 416     | Fatima et al. (2007) |
| **Median (n = 12)**       | 35.0       | 57.5       | 395     |                     |

### Global data (surface soils)

| Location                  | $^{226}$Ra | $^{232}$Th | $^{40}$K | References/Comments |
|---------------------------|------------|------------|---------|---------------------|
| **Max.**                  | 199        | 264        | 1216    | Liu et al. (2015)   |
| **SD (1σ)**               | 36.3       | 49.8       | 721     | Dai et al. (2022)   |
| **RSD (%)**               | 54.7       | 34.3       | 440     |                     |
| **Median**                | 12.6       | 16.0       | 133     |                     |
| **Min.**                  | 8.0        | 8.0        | 252     | Amin et al. (2008)  |
| **Surface soils of Bangladesh** |           |            |         |                     |
| **Max.**                  | 24.8       | 35.0       | 345     |                    |
| **SD (1σ)**               | 14.7       | 17.1       | 222     |                    |
| **RSD (%)**               | 58.7       | 34.3       | 27.3    |                    |
| **Median**                | 8.0        | 8.0        | 252     |                    |

Radioactivity after 2000

| Location                  | $^{226}$Ra | $^{232}$Th | $^{40}$K | References/Comments |
|---------------------------|------------|------------|---------|---------------------|
| **Max.**                  | 54.5       | 91.1       | 287     | Aroguno et al. (2009) |
| **SD (1σ)**               | 26.8       | 36.8       | 493     | Karmanan et al. (2009) |
| **RSD (%)**               | 50.7       | 48.6       | 560     | Caijic et al. (2015)  |
| **Median**                | 12.6       | 17.1       | 222     |                    |

In the absence of any nuclear installation and agricultural activities, anthropogenic origin(s) of U (corresponding to $^{226}$Ra as well) in the urban environment is unlikely. So, for the dust samples at the site D-8, 10, 21, and 23, the U-enrichment in classroom dusts can also be the sources of relatively lower mean-Th/U ratio in dusts. On contrary, non-responsive and immobile characteristics of Th towards the geo-environmental ruling factors can be the sources of relatively lower mean-Th/U ratio in dusts.

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adsorbed in the clays (Kabata-Pendias, 2010; Rachkova et al., 2010). Hence, this adsorption of K\(^{+}\) ions in clays took place until the limit being saturated while the extra K\(^{+}\) ions (water-soluble) percolated through the soil of sub-surface. Hence, the loosely-bound soil in the surface become depleted in K in comparison to the corresponding crustal value.

3.3. Radiological risks assessment

Human health may have adverse effects owing to the exposure of ionizing radiations from primordial radionuclides (Habib et al., 2019a, 2019b, 2022). Primordial radionuclides are the sources of more than 80% radiation exposures in the ambient environment (UNSCEAR, 2000). Inhalation is quite significant exposure route of radiation compared to the external exposure route through dermal exposure. The gaseous progenies of \(^{232}\)Th and \(^{238}\)U existing in the ambient environment can cause the internal exposure. The gaseous decay products of \(^{232}\)Th and \(^{238}\)U are thoron (\(^{220}\)Rn; half-life: 55.6 s) and radon (\(^{222}\)Rn; half-life: 3.8 days), respectively which are usually undergone a dilution process with the gases in the atmosphere before entering the human body. Moreover, thoron cannot enter in the human body due to its very short half-life, but radon, after dilution can easily enter into the body by inhalation. However, dust-particles through inhalation can enter into the lungs with accompanying primordial radionuclides, where \(\alpha\)-particles with different energies were released from the \(^{232}\)Th & \(^{238}\)U decay series. In this case, the contribution of thoron cannot be ignored as it emits considerable amount of \(\alpha\)-radiation from \(^{212}\)Bi (6.1 MeV) and \(^{212}\)Po (8.8 MeV). Such alpha radiations with higher energies (even with very low concentration) are capable of breaking the double-strand of DNA, which cause carcinogenic impact on human body.

Besides the qualitative radiological hazard assessment, radiological indices such as absorbed gamma dose rate (D), radium equivalent activity (Raeq), annual effective dose rate (EAED), external and internal hazard indices (Hex & Hin), gamma representative level index (\(I_\gamma\)), & ELCR are utilized to assess the radiological hazards with comprehensible quantitative processes (Table 5) (Figure 3a–e). Raeq is the collective weighted of the radioactivities of \(^{226}\)Ra, \(^{232}\)Th, & \(^{40}\)K, which is concomitant with the internal & external \(\gamma\)-doses and accompanied with the theory that 4810 Bq.kg\(^{-1}\) of \(^{40}\)K, 370 Bq.kg\(^{-1}\) of \(^{226}\)Ra, and 259 Bq.kg\(^{-1}\) of \(^{232}\)Th each of the radionuclides are generating the similar \(\gamma\)-dose rate. In this study, values of Raeq ranged 100–318 Bq.kg\(^{-1}\) with a mean of 183 Bq.kg\(^{-1}\). Nevertheless, considering the annual dose-criterion, \(I_\gamma\) ranges from 0.75 to 2.22 with a mean of 1.31 ± 0.37. Only 17.4% (D-8, 21–23) sampling locations have \(I_\gamma\) value within permissible value.
Table 5. Calculated radiological risk indices, e.g., Radium equivalent activity (Raeq), External hazard index (Hex), Internal hazard index (Hin), Absorbed dose rate (D), Annual effective dose rate (AEDE), Gamma representative level index (Iγ) of 0.105, Excess lifetime cancer risk (ELCR) for the dust samples collected from the classrooms of schools (Mirpur, central Bangladesh).

|    | Raeq [Bq kg⁻¹] | Hex [γ Gy h⁻¹] | Hin [Sv Gy⁻¹ h⁻¹] | D [Sv y⁻¹] | AEDE [mSv y⁻¹] | Iγ | ELCR [Sv y⁻¹] |
|----|---------------|----------------|-------------------|------------|----------------|----|---------------|
| D-1| 157           | 0.42           | 0.57              | 73.3       | 0.090          | 1.14| 3.15 × 10⁻⁴  |
| D-2| 280           | 0.76           | 1.20              | 130.8      | 0.160          | 1.98| 5.61 × 10⁻⁴  |
| D-3| 174           | 0.47           | 0.74              | 81.6       | 0.100          | 1.23| 3.50 × 10⁻⁴  |
| D-4| 237           | 0.64           | 0.88              | 110.3      | 0.135          | 1.71| 4.74 × 10⁻⁴  |
| D-5| 181           | 0.49           | 0.63              | 85.0       | 0.104          | 1.33| 3.65 × 10⁻⁴  |
| D-6| 179           | 0.48           | 0.73              | 85.0       | 0.104          | 1.30| 3.65 × 10⁻⁴  |
| D-7| 222           | 0.60           | 0.90              | 104.4      | 0.128          | 1.59| 4.48 × 10⁻⁴  |
| D-8| 128           | 0.25           | 0.41              | 60.6       | 0.074          | 0.95| 2.60 × 10⁻⁴  |
| D-9| 162           | 0.44           | 0.60              | 76.6       | 0.094          | 1.19| 3.29 × 10⁻⁴  |
| D-10| 143           | 0.39           | 0.46              | 67.5       | 0.083          | 1.06| 2.90 × 10⁻⁴  |
| D-11| 154           | 0.42           | 0.64              | 72.6       | 0.089          | 1.10| 3.12 × 10⁻⁴  |
| D-12| 159           | 0.43           | 0.67              | 76.1       | 0.093          | 1.15| 3.26 × 10⁻⁴  |
| D-13| 277           | 0.75           | 1.27              | 128.8      | 0.158          | 1.92| 5.53 × 10⁻⁴  |
| D-14| 180           | 0.49           | 0.73              | 83.9       | 0.103          | 1.28| 3.60 × 10⁻⁴  |
| D-15| 175           | 0.47           | 0.72              | 82.1       | 0.101          | 1.25| 3.53 × 10⁻⁴  |
| D-16| 188           | 0.51           | 0.88              | 87.2       | 0.107          | 1.30| 3.74 × 10⁻⁴  |
| D-17| 157           | 0.42           | 0.58              | 73.6       | 0.090          | 1.14| 3.16 × 10⁻⁴  |
| D-18| 205           | 0.55           | 0.82              | 93.9       | 0.115          | 1.43| 4.03 × 10⁻⁴  |
| D-19| 318           | 0.86           | 1.39              | 147.3      | 0.181          | 2.22| 6.32 × 10⁻⁴  |
| D-20| 187           | 0.50           | 0.67              | 86.5       | 0.106          | 1.34| 3.71 × 10⁻⁴  |
| D-21| 100           | 0.27           | 0.30              | 47.3       | 0.058          | 0.75| 2.03 × 10⁻⁴  |
| D-22| 114           | 0.31           | 0.53              | 53.0       | 0.065          | 0.79| 2.27 × 10⁻⁴  |
| D-23| 122           | 0.33           | 0.37              | 56.2       | 0.069          | 0.89| 2.41 × 10⁻⁴  |
| Mean (n = 23)| 183 | 0.49 | 0.73 | 85.4 | 0.105 | 1.31 | 3.66 × 10⁻⁴ |
| SD (1σ)| 54 | 0.15 | 0.27 | 25.0 | 0.031 | 0.37 | 1.07 × 10⁻⁴ |
| RSD (%)| 29.8 | 29.8 | 37.8 | 29.3 | 29.3 | 28.3 | 29.3 |
| Median | 175 | 0.47 | 0.67 | 82.1 | 0.101 | 1.25 | 3.53 × 10⁻⁴ |
| Min. | 100 | 0.27 | 0.30 | 47.3 | 0.058 | 0.75 | 2.03 × 10⁻⁴ |
| Max. | 318 | 0.86 | 1.39 | 147.3 | 0.181 | 2.22 | 6.32 × 10⁻⁴ |
| Recommended | 370 | <1 | <1 | 55 | 0.46 | 1.00 | 2.90 × 10⁻⁴ |

* Khan et al. (2022b).

Typical radiological risk indices merely consider the external origins of radionuclides and accompanied ionizing-radiation as well as inhalation of radioactive gaseous progenys (internal exposure). Nevertheless, calculated indices for ionizing-radiation-risk estimation do not take into account of the ingress of radionuclides’ sources (classroom-dusts) into the human body (lungs) through respiratory system (by breathing), where radioactive progenys of 232Th & 238U release α-particles with variable energies. For external radionuclides’ sources, effects of such α-particle appear insignificant, as the α-particles can be impeded by dermal hindrance. Nevertheless, internal alpha-particles radiation are not obviously being impeded and can result severe harm to the biological cells. Hence, the estimated radiological hazards denote merely the lowermost limits of radiological health risks for the considered classroom-dusts.

### 3.4. Implications for Bangladesh’s case and potential mitigation approaches

Bangladesh is the 8th-most populous country in the world and more than 165 million people live in an area of 148,460 square kilometres. According to the United Nations (United Nations, World Population Prospects, 2022), the present population of Dhaka metro area in 2022 is about 22,478,000 which is an increase of 3.39% from 2021. Bangladesh is on a way to graduating from the UN’s Least Developed Countries (LDC) list in 2026. Keeping this view, Bangladesh has taken a number of development projects specially on the infrastructural side like the...
Figure 3. Distributions of radiological indices in central Bangladesh: (a) spatial distributions of radium equivalent activity (Ra$_{eq}$ in Bq.kg$^{-1}$), (b) spatial distributions of excess lifetime cancer risk (ELCR in Sv$^{-1}$), and the spatial variations of (c) Absorbed gamma dose rate (D in nGy.h$^{-1}$), (d) Gamma representative level index ($I_\gamma$) and (e) excess lifetime cancer risk (ELCR in Sv$^{-1}$) are distinguished with the threshold values (green: within permissible limit; red: above permissible limit).
metro-rail project, flyover, and under-pass. Moreover, a number of industries like textiles, garments, and pharmaceutical companies are also located in Dhaka city. Hence, the produced dust from these development works and transportation can affect the environment adversely. The mean concentrations (in Bq kg⁻¹) of ²²⁶Ra (86.0), ²³²Th (43.4), and ⁴⁰K (488) in the classroom-dusts are comparatively greater in comparison to the corresponding world average values (UNSCEAR, 2000) which may cause the carcinogenic and non-carcinogenic health risks. Ahmad (2008) demonstrated that school children in Dhaka have been suffering increased respiratory difficulties due to the elevated level of particulate matter in the ambient air. According to Sakib (2021), minimum 200,000 people could die in Bangladesh due to respiratory diseases and long-term exposure to highly contaminated air. The mean concentration of ²²⁶Ra in Bangladesh from different literature (n – 13) was 34.8 Bq kg⁻¹ (Table 4) but this study found the mean concentration of ²²⁶Ra in Dhaka city is 86.0 Bq kg⁻¹ which may cause serious health issues for the residents, specifically the school going students of Dhaka city. Both children and adults are died due to the adverse effects of air pollution and/or other diseases linked to it have risen sharply in the country. The AQI reported that the average PM₁₀ concentrations in Bangladesh is 15.4 times higher compared to the WHO annual air quality guideline (AQI Report, 2021) value 2021 and about 13–22% of deaths in this area are associated with the air pollution exposure. So, the air containing dust adversely affects the environment by settling down the indoor establishments. This study presents the worst-case scenario by selecting roadside educational institutions residing in highly dense demographic areas of Dhaka city, and a greater number of students have been considered. Obtained data from this study represent that produced dust from construction work and movement of transportation contained radioactive nuclides which have significant radiological health hazards for school-going children. Throughout this study ‘potential health risk impacts due to the NORMs in dust particles’ are brought into the daylight for a developing country like Bangladesh.

NORMs are the inherent geochemical constituents of the dust samples. So, to reduce the radiological health risks originating from the dust particles, utter concentration should be given in reducing dust production. Vehicular and construction-related emissions are a significant source of dust production which should be reduced. In doing so, dispersion of dust particles may be reduced by spraying water in the premises of schools and nearby roads, especially during the dry season (Wallace and Cheung, 2013). Additionally, demolitions of older establishments and construction works should be covered to reduce dust dispersion. Nevertheless, construction personnel are mostly unaware of the carcinogenic health impacts of dust (Wu et al., 2016). Therefore, one of the first steps to achieving successful dust pollution control is to improve public awareness regarding this issue (Iahir et al., 2005). Relocations of educational institutions far from high traffic areas to more green areas, could be another approach to reduce these health risks. However, such relocation may not be economically viable. Herein, the arrangement of air ventilation and filtration devices, monitoring air quality by low-cost devices, etcetera can be installed to reduce the exposure of students to dust particles (Oliveira et al., 2019). Additionally, personal health consciousness, like wearing a mask could be another effective measure to elevate the radiological health risks originating from the dust. Furthermore, tree plantation in and around educational institutions can reduce the entrance of dust particles into the classrooms (Zhang et al., 2017; Serbula et al., 2012). In such cases, leafy trees can act as natural dust filters. Finally, proper environmental regulations should be strictly monitored to reduce the industrial emissions of dust materials (Wu et al., 2016; Zhang et al., 2015, 2017).

4. Conclusion

For the first time, this work discovered the presence of NORMs-concentrations in the classroom-dusts collected from various educational institutions of central part of Bangladesh. The mean NORMs concentrations in the dust samples are higher in comparison to the associate world mean value, especially the activity of ²²⁶Ra is ~2.5 times higher. The NORMs’ radioactivities of this present study are compared to the activity of surface soils of different countries round the world, which correspondingly unveiled the enrichment of naturally occurring primordial radionuclides in the classroom-dusts relative to the pedosphere surface. Variation of local-geochemistry, variable solubility-based elemental fractionations, leaching, chemical weathering, adsorption, followed by transference of aerodynamic particles control the concentration of NORMs’ abundances in the studied classroom-dusts.

The typical measures of radiological indices evaluate the radiological risks. The average values of Hₐ, Hₘ, Raₐq, and ECLR were within the corresponding permissible limits, whereas the mean values of Iₑ, D, and ECLR were surpassed the recommended safety limits significantly. Albeit the present quantitative approach demonstrated merely the lowermost levels of radiological health risks, overlooking the issue of NORMs’ comprising dust particle’s ingress into the respiratory system by breathing. However, COVID-19 pandemic compelled us to wear mask, which might have a positive impact on hindering the ingress of dust particles into the respiratory systems. Herein, this study can draw the public awareness and the policy maker’s attention regarding the radiological hazards of dust on the school going students. This work eventually invokes the construction works and urbanization processes with limited production of dust materials.

Declarations

Author contribution statement

Md. Joynal Abedin: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Rahat Khan: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We are sincerely expressing our gratitude to the personnel who were involved in sampling, experiment and research reactor operation.

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