

Assessment of the radiological hazards of sand sediments collected from streams and streamlets of the uranium deposit areas in West Khasi Hills District, Meghalaya, India

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Abstract Primordial radionuclides in sand sediments that are often used as constructing materials are one of the sources of radiation hazard in dwellings. Activity concentrations of the primordial radionuclides of ^{40}K , ^{226}Ra and ^{232}Th have been measured in sand sediments collected from streams and streamlets lying within and around the uranium mineralization deposit blocks of Kylleng-Pyndensohiong, Mawthabah Areas of West Khasi Hills District, Meghalaya, India. The technique of gamma-ray spectroscopy using a NaI(Tl) detector with a PC-based multi channel analyser was applied for determination of the activity concentrations. The activity of the sand sediments obtained in this study ranges from 95.3 to 1,088.8 Bq kg⁻¹ for ^{40}K ; 38.3 to 784.1 Bq kg⁻¹ for ^{226}Ra and 78.0 to 316.1 Bq kg⁻¹ for ^{232}Th . Sand sediments from two sampling locations lying within the mineralization zone show highest concentrations of these radionuclides. The radiological hazards of the sand sediments were calculated using various models given in the literature. The radium equivalent activity was found to be higher than the accepted standard criterion value of 370 Bq kg⁻¹ and the values of external and internal hazard indices were also found to be higher than unity in these two sampling locations. Besides these two sampling locations, a sampling location lying at a nearby distance from the mineralization zone also exhibits hazard indices values greater than unity.

Keywords Primordial radionuclides · Sand sediments · Gamma-ray spectrometer · Uranium deposit area · Hazard indices: Meghalaya, India

Introduction

All living organisms are continually exposed to ionizing radiation, which has always existed naturally. The sources of that exposure are cosmic rays that come from outer space and from the surface of the sun, terrestrial radionuclides that occur in the Earth's crust, in building materials and in air, water and foods and in the human body itself (UNSCEAR 2000). The terrestrial or primordial radionuclides have sufficiently longer half-lives, so that they survived since their creation and keep decaying to attain the stable state and producing ionizing radiation in various degrees (Narayana et al. 2005). These radionuclides belong to the ^{238}U (half life: 4.46×10^9 years) and ^{232}Th (half life: 1.41×10^{10} years) series as well as the radioisotope of ^{40}K (half life: 1.23×10^9 years). Gamma radiation from these radionuclides represents the main external source of irradiation of the human body (Obed et al. 2005; Shukla et al. 2001; Tzortzis et al. 2003).

Determination of radioactivity content in building materials like sand sediments is very important as these materials are used for walls, roof and flooring of the room (Ramkumar et al. 2007). They are also vital in the assessment of possible radiological hazards to human health. Naturally occurring radionuclides in building materials are a source of external and internal exposure in dwellings (Amrani and Tahtat 2001). Human beings in houses are exposed externally to gamma radiation arising from building materials and internally due to inhalation

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emitted from radon, thoron, and their respective progenies (Labidi et al. 2006; Miles and Appleton 2005; Organo and Murphy 2007). The radionuclides, radon (^{222}Rn ; half life: 3.8 days) and thoron (^{220}Rn ; half life: 56 s), from the ^{238}U and ^{232}Th decay chains are noble gases produced by the decay of their immediate respective parent nuclides ^{226}Ra (half life: 1,620 years) and ^{224}Ra (half life: 3.8 days) present in common rocks, uranium ores and soils (Fleischer 1997). The radon and thoron decay products are radioactive isotopes of polonium, bismuth, lead and thallium which are produced by the decay of radon isotopes (Porstendorfer 1994). These daughter products, being the isotopes of heavy metals get attached to the existing aerosol particles in the atmosphere. Radon and thoron in indoor environment mainly originates from emanation of the gases from walls, floors, and ceilings. (Ramachandran et al. 2003) reported that most building materials have 1,000–10,000 times higher gas concentrations in their pore spaces than in the atmosphere which were permanently maintained by the continuous decay of its parent nuclide. Buildings, especially with low ventilation rates sealed for saving energy have strongly increased radon and radon daughter productions (Porstendorfer 1994). The dose rate varies depending upon the concentrations of the primordial radionuclides, which in turn depend upon the geological origin of the rock or soil of which those building materials are composed (Mirza et al. 1991; Tufail et al. 2007).

Kylleng-Pyndensohiong, Mawthabah (KPM) Areas near Domiasiat in West Khasi Hills district of Meghalaya, India, about 130 km south–west of Shillong, has been established as the first sandstone-type uranium deposit in India. The uranium deposit in this area is confined to the Lower Mahadek Formation comprising poorly to moderately sorted Quartz arenite with organic matter (Sinha 2005). In this paper, measurement of natural radioactivity of sand sediments collected from streams and streamlets (locally known as *wah* and *wahduid*) within and adjacent to the mineralization zone were taken up and results are discussed in the light of the criteria formula for acceptable radiation dose rate attributed to building materials. Radium equivalent activity and other hazard indices were assessed based on accepted specific criteria formulated for the evaluation of the radiological impact dose rates of building materials.

Materials and methods

Sampling and sample preparation

Sediment samples were taken from ten sampling locations (SL), each of which contains six sampling points, located

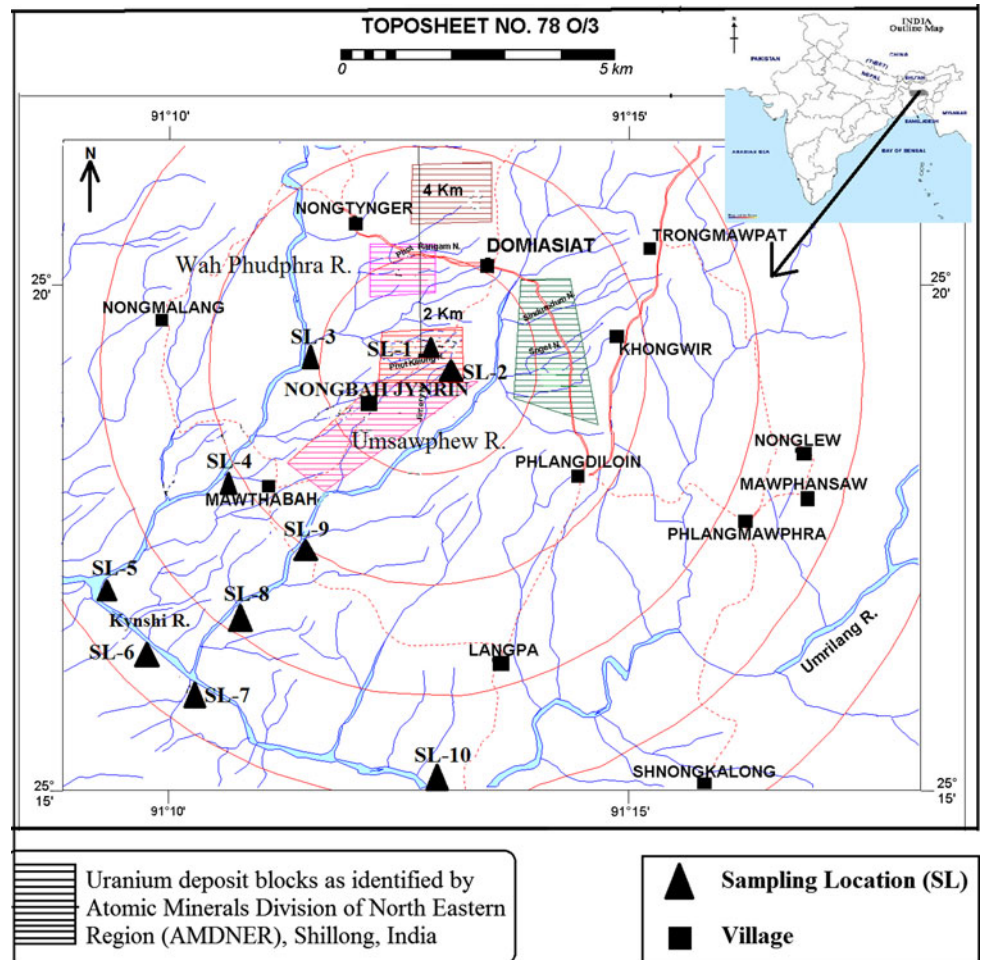
within and around the uranium deposit areas of KPM, Meghalaya, India (Fig. 1). The sediment samples are a mixture of sand and silt. Each of the sampling points in a particular sampling location was selected at a distance of 30–40 m apart, either at the left or right side of the streams and streamlets. The sediments were collected at a depth of 0–10 cm. It is to be noted that sampling was carried out during the post-monsoon period (November) where all these sampling points can be accessed. After collection, each sample was dried in an oven at 100–110°C for about 24 h. They were then crushed, pulverized to a fine powder and sieved through a 2 mm mesh-sized sieve. About 400 g of the homogenized sediment samples were sealed airtight in cylindrical containers (7.5 cm diameter and 8.5 cm height) and were stored about 4 weeks so that secular equilibrium is attained between ^{226}Ra and its daughter products as well as between ^{228}Th and its daughter products. The containers were filled full for uniform distribution of ^{220}Rn and ^{222}Rn daughter products and to avoid accumulation at the top.

Radioactivity determination

Analysis of ^{40}K , ^{226}Ra and ^{232}Th activity levels in sand sediments were assessed by using a flat type 3" × 3" NaI (Tl) detector housed in a graded lead shield, PC coupled MCA card (PHAST PC-8K MCA, TYPE: MC 1008) and associated relevant electronics. NaI(Tl) coupled gamma-ray spectrometer was calibrated for 0–3,200 keV energy range. Energy calibration and efficiency evaluation of the gamma-spectrometer was done by using standards RGK-1, RGU-1 and RGTh-1 obtained from the International atomic energy agency (IAEA) in the appropriate matrix. The procedure for preparing secondary standards was described elsewhere (Sadasivan 1989). The standards were packed in similar plastic containers, which were used for soil samples storage and counted after allowing time for attaining secular equilibrium.

The sample was placed on top of the detector and the spectrum was acquired for 50,000 s. The counting time was standardized so as to get well-defined peaks of ^{40}K , ^{226}Ra and ^{232}Th in the spectrum (HASL-300 1990), as these are definitely present in any samples in varying amounts so as to get better sensitivity and a good counting statistics. The activity of ^{40}K in the samples was evaluated from the 1,460.8 keV peak, the activity of ^{226}Ra from the 1,764.6 keV gamma line of ^{214}Bi and that of ^{232}Th from the 2,614.5 keV gamma line of ^{208}Tl . The detection limits of the instrument for 50,000 s counting time and 350 g of sample were found out to be 25.3 Bq kg⁻¹ for ^{40}K , 8.5 Bq kg⁻¹ for ^{226}Ra and 9.3 Bq kg⁻¹ for ^{232}Th .

Fig. 1 Map of the study area along with the sampling points



Results and discussions

Natural radionuclides concentration in sand sediments from the study area

Table 1 give the range and mean activity concentrations of ⁴⁰K, ²²⁶Ra and ²³²Th of sand sediments collected from the ten sampling locations (SL) of the study area. As can be seen from Table 1, the primordial radionuclides concentration in stream sediments from different sampling locations differ significantly. The highest activity concentration of the primordial radionuclides in sand sediments was found out to be from SL-2 followed by SL-1. The natural radionuclides activity level in sand sediments of SL-2 was found out to vary in the range of 906.6–1,088.8 Bq kg⁻¹ for ⁴⁰K; 545.7–784.1 Bq kg⁻¹ for ²²⁶Ra and 181.3–316.1 Bq kg⁻¹ for ²³²Th. The average activity concentrations of ⁴⁰K, ²²⁶Ra and ²³²Th in sediments from SL-2 were found out to be 986.1, 649.1 and 251.9 Bq kg⁻¹, respectively. The average activity level of ⁴⁰K, ²²⁶Ra and ²³²Th in sediments from SL-1 was found out to be 487.4, 254.0 and 169.1 Bq kg⁻¹, respectively. The high ²²⁶Ra content in sand sediments of

these two sampling locations is expected since both these sampling points are within the mineralization zone where majority of surface samples has a U₃O₈/eU₃O₈ factor varying from 0.67 to 0.94 (Gupta 1997) thereby indicating surface leaching environment. The term eU₃O₈ is a grade derived from radiometric gamma logging, which commonly requires modification by a disequilibrium factor to generate grades reflective of the true (chemical) U₃O₈ grade of mineralization. The disequilibrium factor reflects the proportion of radiometric response that is due to radiation emitted by daughter products of the uranium decay sequence rather than uranium itself and is commonly related to the maturity of the decay sequence and thus the age of the mineralization. It is to be noted that in SL-2, the streamlet flows over rocks where a part of the uranium ore is exposed to the land surface. In addition, uranium tends to be highly mobile near the surface when compared to thorium and potassium (El-Arabi et al. 2007). Besides this, uranium and thereby radium is also easily oxidized to water-soluble form and can be readily leached from the ore or rocks and re-deposited as sediments. Thus, this explains high ²²⁶Ra concentration in SL-2. Another reason for ²²⁶Ra concentration in SL-2 can also be

Table 1 ^{40}K , ^{226}Ra and ^{232}Th activity concentration of sand sediments from the study area

Sampling location	Activity concentration (Bq kg^{-1})		
	^{40}K	^{226}Ra	^{232}Th
SL-1			
Range	443.0–528.4	211.0–293.1	117.3–213.7
Mean	487.4	254.0	169.1
SD*	34.8	35.9	38.9
SL-2			
Range	906.6–1,088.8	545.7–784.1	181.3–316.1
Mean	986.1	649.1	251.9
SD	76.5	89.4	44.1
SL-3			
Range	129.8–178.9	98.7–122.7	125.7–146.2
Mean	153.9	108.7	135.8
SD	18.5	8.8	8.0
SL-4			
Range	105.2–134.5	62.2–85.4	103.5–152.4
Mean	122.3	74.2	127.0
SD	11.4	9.4	16.2
SL-5			
Range	142.3–184.5	57.1–85.4	87.9–123.7
Mean	164.9	72.6	106.3
SD	14.5	10.2	13.3
SL-6			
Range	101.6–152.3	49.7–79.2	88.7–131.7
Mean	128.6	63.6	110.0
SD	19.9	11.4	17.3
SL-7			
Range	128.0–154.2	59.2–78.4	84.1–101.3
Mean	141.6	68.5	91.6
SD	10.6	6.6	6.3
SL-8			
Range	95.3–123.7	70.8–92.5	78.0–105.4
Mean	110.4	83.1	94.6
SD	10.4	8.7	10.0
SL-9			
Range	187.9–231.5	158.8–191.0	109.3–143.1
Mean	209.1	174.2	125.8
SD	16.1	12.3	13.3
SL-10			
Range	99.7–134.1	38.3–65.3	92.5–121.5
Mean	119.6	49.0	104.5
SD	13.0	10.7	10.0

* *SD* Standard deviation

due to the fact that the sand sediments that settle in the river are silts and sediments which are derived by ore erosion and weathering of rock and soil.

Physically, the area is a gentle southward dipping plateau with deeply cut gorge sections of Umsawphew and Wah Phudphra rivers (Fig. 1) on either side. The general flow of the drainage in the area is towards south–west

(Gupta 1997). The remaining sampling locations (i.e. SL-3 to SL-10) were located on both these rivers and along the Kynshi River which finally flows to Bangladesh. In addition, results of the analysis of sand sediments from the remaining seven sampling locations with the exception of sampling location SL-9 show that the activity concentration levels of ^{40}K , ^{226}Ra and ^{232}Th were much smaller

when compared with the first two sampling locations (i.e. SL-1 and SL-2). The activity concentration of ^{40}K , ^{226}Ra and ^{232}Th in sand sediments from these seven locations (excluding SL-9) were found to vary between 95.3 and 184.5 Bq kg^{-1} for ^{40}K ; 38.3 and 122.7 Bq kg^{-1} for ^{226}Ra and 78.0 and 146.2 Bq kg^{-1} for ^{232}Th , sand sediments from SL-8 show the lowest ^{40}K and ^{232}Th activity concentration with average values of 110.4 and 94.6 Bq kg^{-1} while sand sediments from SL-10 (which is at a far-off distance from the mineralization zone) show the lowest activity concentration level of ^{226}Ra with an average value of 49.0 Bq kg^{-1} . The average ^{226}Ra activity level in sand sediments from sampling location SL-9 with an average activity level of 174.2 Bq kg^{-1} was found to be much higher when compared with the other sampling locations excluding SL-1 and SL-2. This high ^{226}Ra concentration in sediments of SL-9 can be due to the fact that this sampling location is located in the downstream of Umsawpew River where several streamlets from the uranium mineralization blocks flow (Fig. 1). Therefore, some of the sediments may have been transported to this sampling point accounting for a much higher ^{226}Ra concentration in sediments. The average activity concentration of ^{40}K in sediments of all sampling locations show a much lower value when compared with the global average value which is 500 Bq kg^{-1} (UNSCEAR 1993) with exception of sand sediments from SL-2 where the activity concentration of ^{40}K is about two times higher than the global average value. As for ^{226}Ra concentration, it was found that with exception of sand sediments of SL-10, the other sampling locations show ^{226}Ra activity levels much higher than the global average value of 50 Bq kg^{-1} (UNSCEAR 1993). The ^{232}Th activity concentration of sand sediments in all the ten sampling locations were found out to be much higher than the global average value of 50 Bq kg^{-1} (UNSCEAR 1993).

Dose rate in air (D_{air}) from sand sediments

The total air absorbed dose rate D_{air} (in nGy h^{-1}) due to the specific activity concentration of ^{40}K , ^{226}Ra and ^{232}Th in different building materials can be computed from the specific activity of natural radionuclides in building materials by using the following equation (UNSCEAR 2000):

$$D_{\text{air}}(\text{nGy h}^{-1}) = 0.0417C_{\text{K}} + 0.462C_{\text{Ra}} + 0.604C_{\text{Th}}$$

where, C_{K} , C_{Ra} and C_{Th} are the activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th , respectively in Bq kg^{-1} for the material. This equation is used for calculating the absorbed dose rate in air at a height of 1 m above the ground. From Table 2, the absorbed dose rate in air due to sand sediments was found to be highest from SL-2 with values ranging

between 1,016.7 and 1,154.8 nGy h^{-1} and an average value of $1,085.2 \pm 47.3 \text{ nGy h}^{-1}$. The average relative contribution of ^{40}K , ^{226}Ra and ^{232}Th contents to the absorbed dose rate in air was calculated and found out to be 8.3% from ^{40}K , 60.7% from ^{226}Ra and 31.0% from ^{232}Th which means that the absorbed dose in air from sand sediments from this sampling location is primarily from ^{226}Ra , the daughter product of ^{238}U . Sediments from SL-1 also show a high absorbed dose rate followed by SL-9 with average values of 239.8 ± 31.3 and $165.1 \pm 5.5 \text{ nGy h}^{-1}$, respectively. Amongst the remaining sampling locations, it was found that sediments from SL-10 show the lowest absorbed dose rate with values ranging between 78.9 and 108.5 nGy h^{-1} with an average value of $90.7 \pm 10.3 \text{ nGy h}^{-1}$. The percentage dose contribution due to the primordial radionuclides to the absorbed dose rate from all the sampling locations along with the UNSCEAR value is presented in Fig. 2.

Radium equivalent activity (Ra_{eq})

An index Ra_{eq} , called the radium equivalent activity is also presented in Table 2. To compare the activity concentration and the radiological effects of building materials like sand sediments which contain ^{40}K , ^{226}Ra and ^{232}Th , the radium equivalent activity Ra_{eq} as a common index has been introduced (Beretka and Mathew 1985) which is calculated through the following relation:

$$Ra_{\text{eq}} = C_{\text{Ra}} + 1.43C_{\text{Th}} + 0.077C_{\text{K}}$$

where, C_{Ra} , C_{Th} and C_{K} are the specific activities of ^{226}Ra , ^{232}Th and ^{40}K in Bq kg^{-1} , respectively. Radium equivalent activity is the weighted sum of the activities of ^{226}Ra , ^{232}Th and ^{40}K based on the assumption that 370 Bq kg^{-1} of ^{226}Ra , 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K deliver equal gamma dose rates (Krisiuk et al. 1971). From the radiological point of view, the maximum tolerable value of $Ra_{\text{eq}} \leq 370 \text{ Bq kg}^{-1}$ (OECD 1979). If $Ra_{\text{eq}} < 370 \text{ Bq kg}^{-1}$, then the external dose rate will be below 1.5 mGy year^{-1} (Krisiuk et al. 1971). Radium equivalent activity has been calculated and as can be seen from Table 2, the Ra_{eq} values of sand sediments from SL-1 and SL-2 were higher than the recommended limit with average values of 533.4 and 1,085.2 Bq kg^{-1} , respectively. Besides these two sampling locations, SL-9 shows significantly higher Ra_{eq} values, compared to sediments of SL-3 to SL-8 and SL-10. It even exceeds the OECD limitation value.

External hazard index (H_{ex})

The concept of the hazard index (HI) has been around for a number of years and has been used for evaluation of

Table 2 Absorbed dose and values of hazard indices for sand sediments from the study area

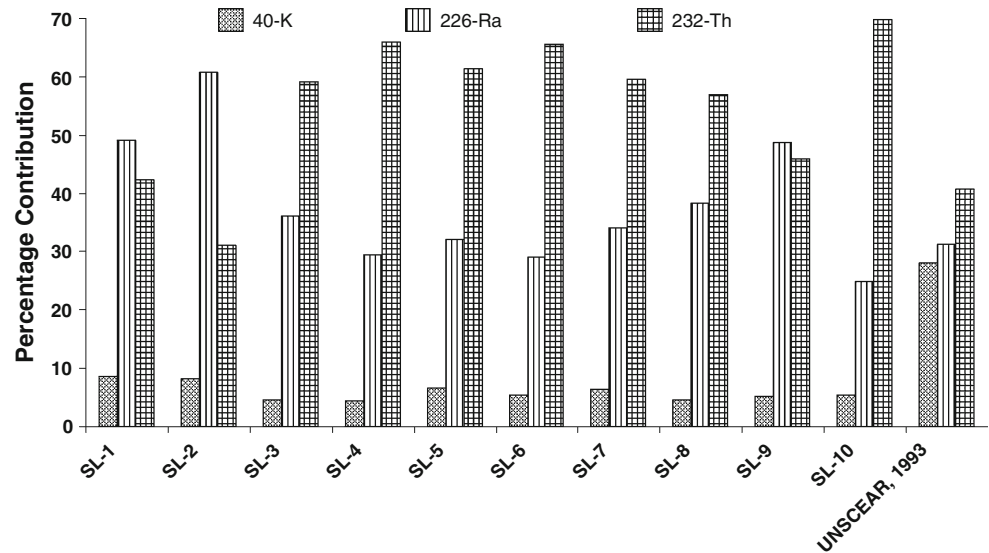
Sampling location	Hazard indices			
	ADR (nGy h ⁻¹)	Ra _{eq} (Bq kg ⁻¹)	H _{ex}	H _{in}
SL-1				
Range	202.9–284.0	449.1–634.8	1.2–1.7	1.8–2.5
Mean	239.8	533.4	1.4	2.1
SD*	31.3	72.0	0.2	0.3
SL-2				
Range	460.6–525.4	1016.7–1154.8	2.7–3.1	4.3–5.1
Mean	493.1	1085.2	2.9	4.7
SD	23.1	47.3	0.1	0.3
SL-3				
Range	128.0–148.2	290.7–336.4	0.8–0.9	1.1–1.2
Mean	138.7	314.7	0.9	1.1
SD	8.2	18.4	0.1	0.1
SL-4				
Range	96.0–137.1	219.0–313.7	0.6–0.9	0.8–1.1
Mean	116.1	265.2	0.7	0.9
SD	13.9	31.9	0.1	0.1
SL-5				
Range	86.1–121.1	195.0–275.0	0.5–0.7	0.7–1.0
Mean	104.6	237.4	0.6	0.8
SD	12.0	27.5	0.1	0.1
SL-6				
Range	86.3–120.5	196.4–275.1	0.5–0.7	0.7–1.0
Mean	101.2	230.8	0.6	0.8
SD	15.4	35.3	0.1	0.1
SL-7				
Range	83.5–99.5	189.3–225.8	0.5–0.6	0.7–0.8
Mean	92.9	210.5	0.6	0.8
SD	5.5	12.5	0.1	0.1
SL-8				
Range	90.8–109.5	204.9–248.1	0.6–0.7	0.8–0.9
Mean	100.1	226.8	0.6	0.8
SD	7.9	18.0	0.1	0.1
SL-9				
Range	158.8–171.3	353.6–383.5	0.9–1.0	1.4–1.6
Mean	165.1	370.1	1.0	1.5
SD	5.5	13.1	0.1	0.1
SL-10				
Range	78.9–108.5	180.7–248.1	0.5–0.7	0.6–0.9
Mean	90.7	207.7	0.6	0.7
SD	10.3	23.5	0.1	0.1

* SD Standard deviation

potential hazards associated with both radiological and non-radiological hazards. In either situation, the hazard index represents the summation of ratios, sometimes referred to as hazard quotients, each quotient being a measured or otherwise determined value for a particular contaminant (the value might be either a quantity of material or a concentration) divided by a reference value

for that contaminant. In the case of radiological contaminants in soil and/or building materials, the hazard quotient for each contaminant is usually expressed as the concentration in the medium of interest (soil or building material) divided by the reference concentration for the contaminant in that medium. The reference value is of a magnitude that, under model assumptions, will result in

Fig. 2 Percentage dose contribution to the absorbed dose rate due to primordial radionuclides concentration from sand sediments of the study area along with UNSCEAR value



an acceptable dose equivalent over some specified time interval.

According to International Commission on Radiological Protection (ICRP 1977), the upper limit of radiation dose arising from building materials was fixed as 1.5 mSv year⁻¹. For limiting the radiation dose to this value, Krieger (1981) proposed the following conservative model based on infinitely thick walls without doors and windows to serve as a criterion for calculation of external hazard index (H_{ex}), which is defined as:

$$H_{ex} = (1/370)C_{Ra} + (1/259)C_{Th} + (1/4,810)C_K$$

where, C_{Ra} , C_{Th} and C_K are the specific activities of ²²⁶Ra, ²³²Th and ⁴⁰K, respectively, in terms of Bq kg⁻¹ for the material. According to Ramkumar (Ramkumar et al. 2007), the value of this index must be less than unity so that the annual radiation dose arising from building materials is less than the prescribed limit of 1.5 mSv. The maximum value of $H_{ex} = 1$ corresponds to the upper limit of Ra_{eq} (i.e. 370 Bq kg⁻¹). From Table 2, it can be seen that calculated average H_{ex} values of sand sediments from SL-1 and SL-2 was 1.4 and 2.9, respectively, thereby indicating $H_{ex} > 1$. Sediments from the remaining sampling locations exhibit $H_{ex} \leq 1$.

Internal hazard index (H_{in})

In addition to external irradiation, radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by the internal hazard index (H_{in}), which is given by the following equation (Krieger 1981):

$$H_{in} = (1/185)C_{Ra} + (1/259)C_{Th} + (1/4,810)C_K$$

where, C_{Ra} , C_{Th} and C_K are the specific activities of ²²⁶Ra, ²³²Th and ⁴⁰K, respectively, in Bq kg⁻¹ for the material.

For safe use of a material in the construction of dwellings, H_{in} must be less than unity. From Table 2, it is seen that H_{in} values of the sand sediments investigated in this study was found to be greater than unity from sampling locations SL-1, SL-2, SL-3 and SL-9 with respective average values of 2.1, 4.7, 1.1 and 1.5, thereby indicating that the sand sediments are not safe to be used as building materials. Sediments from the other remaining sampling locations (SL-4, SL-5, SL-6, SL-7, SL-8 and SL-10) indicate H_{in} values very close to unity. A graphical representation of both the calculated external and internal hazard index values along with the threshold limiting value is represented in Fig. 3.

Conclusion

The natural radioactivity concentrations of ⁴⁰K, ²²⁶Ra and ²³²Th from sand sediments of ten sampling locations lying within and around the uranium mineralization area of Kylleng-Pyndensohiong, Mawthabah Areas have been measured using the technique of gamma-ray spectrometry with NaI(Tl) detector. High ²²⁶Ra activity concentration was observed from sediments of two sampling locations (i.e. SL-1 and SL-2) lying within the mineralization block with respective average values of 254.0 and 649.1 Bq kg⁻¹ and was also found to be very much higher when compared with the global average value of 50 Bq kg⁻¹. Another sampling location (SL-9) located at a much closer distance to the mineralization zone also exhibit high ²²⁶Ra activity concentration with an average value of 174.2 Bq kg⁻¹ when compared with the other remaining sampling locations lying outside the mineralization zone. The calculated values of absorbed dose rate in air due to ⁴⁰K, ²²⁶Ra and ²³²Th from sand sediments in the study area was found out to be highest from SL-2 with an average value of

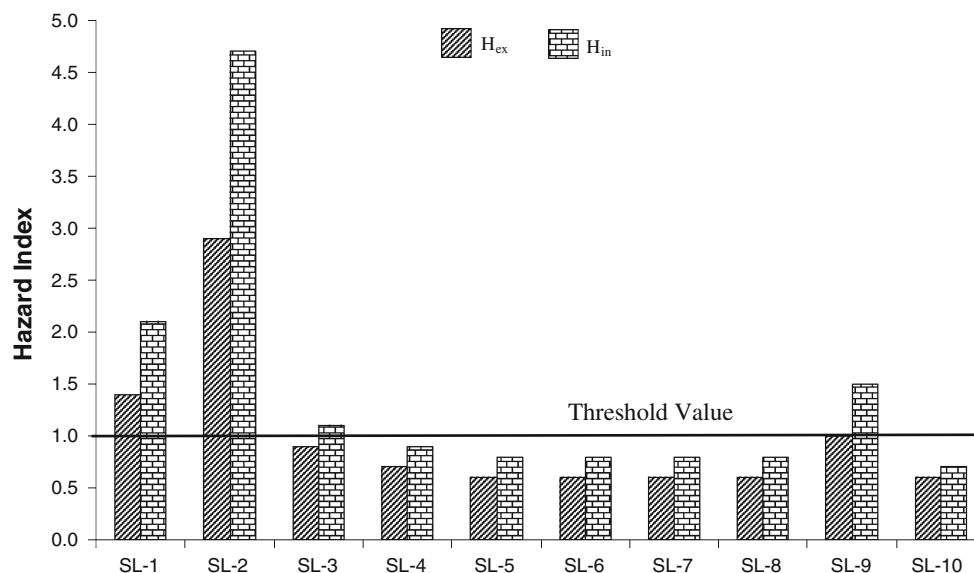


Fig. 3 Calculated external and internal hazard index values from sand sediments of the study area

493.1 nGy h⁻¹ followed by SL-1 with an average value of 239.8 nGy h⁻¹. The lowest value of the absorbed dose rate in air due to the primordial radionuclides was identified in sediments of SL-10 which is at a far-off distance from the mineralization zone with an average value of 90.7 nGy h⁻¹. The radium equivalent activity in sand sediments from the two sampling locations lying within the mineralization zone was found to be higher than the recommended limit value of 370 Bq kg⁻¹ which results in an annual exposure dose of more than 1.5 mSv to the inhabitants. Sediments from the remaining sampling locations show Ra_{eq} values of ≤370 Bq kg⁻¹. External hazard index (H_{ex}) and internal hazard index (H_{in}) in sand sediments from the study area was found to be higher than unity from sampling locations SL-1 and SL-2 with SL-3 and SL-9 also showing H_{in} values greater than unity. Other sampling locations show H_{ex} and H_{in} values <1. Based on the criterion formula for gamma activity, the results obtained from the study indicate that the sand sediments obtained from streams and streamlets within the mineralization zone of the uranium deposit areas of Kylleng-Pyndensohiong, Mawthabah should not be used for building construction. Sand sediments from streams and streamlets lying outside the mineralization zone can be used for building construction but with a special care of mixing them with sand sediments of very low radioactivity content.

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