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Assessment of radiological hazards due to soil and building materials used in Mirpur Azad Kashmir; Pakistan

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Background: Health hazards associated with exposure due to the natural radioactivity which is a part of our physical environment are of great concern. In order to assess the risks associated with exposure due to the natural radioactivity in soil and building materials, extensive studies have been carried out all over the world. The most commonly encountered radionuclide's are ^{238}U, ^{232}Th, their decay products and ^{40}K. *Materials and Methods:* In order to study the concentration of these radionuclides soil, sand, gravel aggregates, bricks and marble, samples were collected from different sites and local suppliers of the district Mirpur, Azad Kashmir (Pakistan). ^{226}Ra, ^{232}Th, and ^{40}K activities in the collected samples were measured using HPGe detector. The measured specific radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the studied samples ranged from 10 ±1 to 47 ± 2, 18 ± 1 to 75 ± 4 and 40 ± 3 to 683 ±3 Bq.kg^{-1}, respectively. *Results:* From the measured activity concentration, radium equivalent activity, external and internal hazard indices, gamma and alpha indices, terrestrial absorbed dose and annual effective dose were calculated. Maximum value of radium equivalent activity of 197.1 ± 9 Bq.kg^{-1} was observed in soil sample whereas minimum value of 45.9 ± 2 Bq.kg^{-1} was found in gravel aggregates. Relatively higher mean values of hazard indices were found in brick samples. Annual effective dose varied from 0.06 ± 0.01 to 0.47 ± 0.02 mSv.y^{-1}. *Conclusion:* Current values of annual effective dose, radium equivalent activity and hazard indices have been found to be within the recommended limits. **Iran. J. Radiat. Res., 2011; 9(2): 77-87**

Keywords: *Building materials, radiological hazards, radium equivalent activity, annual effective dose, external and internal hazard indices.*

INTRODUCTION

It is a well known fact that rocks and soil contain trace amounts of uranium and thorium with their progenies which makes most of the naturally occurring materials slightly radioactive. In some cases, concentration of radioactive elements in building materials (made up of earth's strata) may be high enough to result in significant exposure to the general population. Presence of these naturally occurring radionuclides in earth crust strongly depends upon geological and geographical locations (1-4) (e.g., radionuclide concentrations in granite locations are higher relative to sand stones and limestone regions). Building materials (granite, gravel aggregates, bricks, marble, sand, soil) contain few parts per million of uranium and thorium, together with their radioactive progenies and ^{40}K. These radionuclides are considered as direct source of external and internal radiation exposure. ^{40}K is considered as a principal internal source of terrestrial radiations. From a total of 130 g of potassium in an average person weighing 70 kg, there is about 0.0157 g of ^{40}K. Therefore, total activity due to ^{40}K in the body is approximately 0.11 μCi (4.07×10^{3} Bq) (5).

Soil and Building materials are known to contribute towards the radiation doses received by the general population (6-41). Therefore, knowledge of natural radioactivity levels is a pre-requisite in soil and building materials in order to set the standards and national guidelines in the

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light of international recommendations. Hence, the prime objective of this work was to develop a base line reference data of natural radioactive elements present in the soil/building materials of the district Mirpur of the Azad Kashmir; Pakistan and to evaluate their radiological consequence if used in construction of buildings.

Geology of Mirpur

The studied area is underlain by sedimentary rocks of Siwalik Group of non-marine origin, ranging in age from Late Miocene to Pleistocene (figure 1). It is postulated that the sediments of the group were deposited in a slowly sinking basin under fresh water conditions. The total thickness of the sequence is about 5000 meters and constitutes a major portion of the whole Siwalik Group.

Nagri formation

The Nagri Formation is exposed in the north and northeastern part of the mapped area where, it is about 100 to 1450 meters thick and consists of inter-bedded sandstone and clays. It consists of about 70% sandstone and 30% clays. The sandstones are greenish gray to light gray, massive, medium to coarse grained sandstones with subordinate intercalations of reddish brown mudstone, gritty and conglomeratic beds are found mat places. The formation has yielded fairly rich assemblage of vertebrate remains which indicates late middle Miocene to late Miocene age [42, 43].

Dhok pathan formation

The Dhok Pathan Formation is about 1500 to 2250 meters thick in the mapped area. The formation is represented by monotonous cyclic deposition of alternate sandstone and clay beds, exposed towards northern parts of the mapped area. The sandstones are gray, light gray, reddish brown and gleaming white, fine to medium grained, medium to thick bedded, with alternations of orange brown and dull red silty clay. Dhok Patan formation has conglomerate in the form of layers and lenses

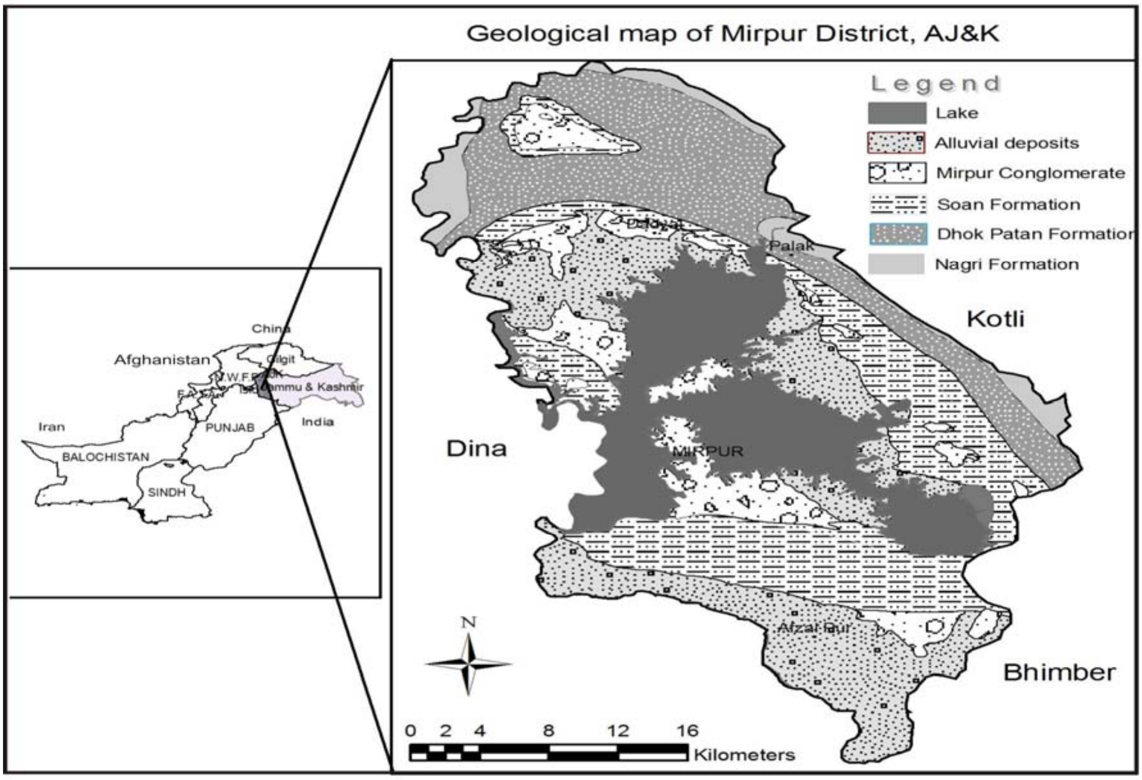

Figure 1. Geological map of Mirpur, Azad Kashmir

and it is the essential character of the upper part. The fauna present in this formation indicates as early to middle Pliocene age [44].

Soan formation

The formation comprised of yellowish gray clay and claystones, greenish gray, soft, massive sandstone and reddish brown clays. The unit consists of interbeds of conglomerate beds and clays. The conglomerate bands mainly consist of pebbles and boulders of limestone, quartzite, porphyritic rocks, sandstone, gneisses, schist, diabase etc. The pebbles and boulders range in size from 5 cm to 30 cm. The age of this formation is late Pliocene to early Pleistocene [44].

Mirpur conglomerates

The Mirpur Conglomerates are more than 250 meters thick and mainly comprised of unsorted conglomerates and mudstones having no bedding pattern. The conglomerates are composed of, unsorted, and well rounded pebbles and boulders of limestone, sandstone, quartzite and volcanic material, which range in size from 5 mm to 200 mm in diameter.

MATERIALS AND METHODS

In order to carry out this study, a total of 44 samples were collected from different locations of the district Mirpur, Azad Kashmir, Pakistan. These included 20 samples of soil, 6 samples of sand, 6 samples of gravel aggregates, 6 samples of bricks and 6 samples of marbles. The collected samples were crushed, sieved and dried at 110 ±1 ^{0}C for 20 h. These samples were then placed in Marinelli beakers and hermitically sealed. These beakers were then placed in an undisturbed position for a period of 60 days in order to attain equilibrium between ^{226}Ra and ^{222}Rn. To measure gamma spectra, a P-type HPGe detector was used. The resolution and relative efficiency of the detector for 1332 keV (^{60}Co) was 2.5 keV and 90 %, respectively. The detector and preamplifier were placed inside a low-background well-type lead shielding and cooled by liquid nitrogen from vertical dipstick cryostat. Energy and efficiency calibration of the detector were performed using standard point sources and mined nuclides gamma reference source (from AEA technology QSA GmH, Germany). Background signals were periodically recorded for the same time period and subtracted from each result obtained. Spectra were collected for about 12 hours in order to get sufficient counts at the desired peaks. ^{226}Ra concentration was determined by means of its progeny photo peaks of gamma-ray lines: ^{214}Pb (295.21 keV, 352 keV) and ^{214}Bi (609 KeV, 1120.29 keV), ^{232}Th was determined through its progeny photo peaks of gamma-ray lines: ^{228}Ac (338.32 keV, 911.21 keV, 968.97 keV) whereas ^{40}K activity was measured directly through its gamma-ray energy peak of 1460.83 keV. The software Personnel Computer Analyzer (PCA-II) was used for the collection of the spectra. The lowest limits of detection (LLD) for ^{226}Ra, ^{232}Th and ^{40}K are found 1.2, 2.1 and 10 Bq kg^{-1} respectively.

RESULTS AND DISCUSSION

Activity concentrations of various radio nuclides ^{226}Ra, ^{232}Th, and ^{40}K were calculated by using the following relation,

$$A=\frac{N_i}{\eta_i \times P_{\gamma i} \times C_i \times t} \quad (1)$$

Where C_i the net counts, t is is the data collection time, $P_{\gamma i}$ is the emission probability and η_i is the efficiency of the detector for the corresponding peak.

The most important aspect is to determine the energy delivered by a radionuclide per unit mass of a substance which is known as specific activity (A_s).

$$A_s = \frac{A}{m} \quad (2)$$

Where "A" is activity concentration (Bq) and m is mass of the sample in kg.

Table's 1-5 shows measured values of specific activities of ^{26}Ra, ^{232}Th and ^{40}K, radium equivalent, external and internal hazard indices, I_γ, I_α, absorbed dose and annual effective dose along with Geometric Mean (GM) ± Geometric Standard Deviation (STDEV) in soil, sand, gravel aggregates, bricks and marble samples.

As may be seen in table 1, activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied soil samples varied from 14±1 to 47±2 Bq kg^{-1} , 26±1 to 75±4 Bqkg^{-1} and 268±12 to 679±30 Bqkg^{-1} with mean values of 27.4±8.4, 52±13, 478±111 Bqkg^{-1} respectively. Maximum activity concentration of the ^{226}Ra and ^{232}Th has been observed in Soil-3 which was collected from the Mirpur University of Sciences and Technology (MUST) site whereas minimum concentration was observed in Soil-7 that was collected from the Chaichyan Mirpur site. Minimum concentration value of ^{40}K was also noted in Soil-7 whereas maximum value was observed in Soil-1 collected from the Industrial Area of the Mirpur Azad Kashmir.

Table 1. Measured values of the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied soil samples collected from the district Mirpur. R_{eq}, H_{ex}, H_{in}, I_γ, I_α, absorbed dose and Annual effective dose values are also given in this table.

Sample Code	^{226}Ra (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})	Ra_{eq}	H_{ex}	H_{in}	I_γ	I_α	D_{air} nGyh^{-1}	Annual effective dose (mSv)
Soil-1	39±2	74±4	679±30	197.10±9	0.53±0.03	0.64±0.03	0.72±0.04	0.19±0.01	94.8±5	0.47±0.025
Soil-2	37±2	66±3	650±28	181.43±9	0.49±0.02	0.59±0.03	0.66±0.03	0.18±0.01	87.4±4	0.43±0.020
Soil-3	47±2	75±4	539±24	195.75±9	0.53±0.03	0.66±0.03	0.70±0.04	0.23±0.01	92.9±5	0.46±0.025
Soil-4	29±1	51±3	494±22	139.97±7	0.38±0.02	0.46±0.02	0.51±0.03	0.14±0.01	67.4±3	0.33±0.015
Soil-5	23±1	40±2	460±20	115.62±6	0.31±0.01	0.37±0.02	0.42±0.02	0.11±0.01	56.1±3	0.28±0.015
Soil-6	25±1	58±3	398±17	138.59±7	0.37±0.02	0.44±0.02	0.50±0.02	0.12±0.01	66.2±3	0.33±0.015
Soil-7	14±1	26±1	268±12	71.82±4	0.19±0.01	0.23±0.01	0.26±0.01	0.07±0.01	34.7±2	0.17±0.010
Soil-8	21±1	40±2	390±17	108.23±5	0.29±0.01	0.35±0.02	0.40±0.02	0.10±0.01	52.2±3	0.26±0.015
Soil-9	24±1	47±2	405±18	122.40±6	0.33±0.01	0.40±0.02	0.45±0.02	0.12±0.01	58.8±3	0.29±0.015
Soil-10	26±1	59±3	589±26	155.72±8	0.42±0.02	0.49±0.02	0.57±0.03	0.12±0.01	75.5±4	0.37±0.020
Soil-11	22±1	39±2	342±15	104.10±5	0.28±0.01	0.34±0.02	0.37±0.02	0.10±0.01	49.9±2	0.25±0.010
Soil-12	22±1	42±2	352±15	109.16±5	0.29±0.01	0.35±0.02	0.39±0.02	0.10±0.01	52.3±3	0.26±0.015
Soil-13	32±2	52±3	503±22	145.09±7	0.39±0.02	0.48±0.03	0.53±0.03	0.15±0.01	69.7±3	0.34±0.015
Soil-14	41±2	73±4	474±21	181.89±9	0.49±0.02	0.60±0.03	0.66±0.03	0.20±0.01	86.2±4	0.42±0.020
Soil-15	23±1	54±3	572±25	144.26±7	0.39±0.02	0.45±0.02	0.53±0.03	0.11±0.01	70.2±3	0.34±0.015
Soil-16	25±1	57±3	518±23	146.40±7	0.40±0.02	0.46±0.02	0.54±0.03	0.12±0.01	70.7±3	0.35±0.015
Soil-17	34±2	64±3	562±25	168.79±8	0.46±0.02	0.55±0.03	0.62±0.03	0.17±0.01	81.1±4	0.40±0.020
Soil-18	20±1	41±2	417±18	110.74±6	0.30±0.01	0.35±0.02	0.41±0.02	0.10±0.01	53.6±3	0.26±0.015
Soil-19	38±2	61±3	596±26	171.12±8	0.46±0.02	0.56±0.03	0.62±0.03	0.19±0.01	82.2±4	0.40±0.020
Soil-20	28±1	55±3	610±27	153.62±7	0.41±0.02	0.49±0.02	0.57±0.03	0.14±0.01	74.6±4	0.37±0.020
GM± STDEV	27.4±8.4	52±13	478±111	139±33.7	0.38±0.09	0.45±0.11	0.51±0.12	0.14±0.04	66.9±16.04	0.33±0.08
average	28.50	53.70	490.90	143.09	0.39	0.46	0.53	0.14	68.83	0.34

In sand samples (table 2), specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K has been found to range from 18± 1 to 29±1 Bq kg^{-1} , 30±2 to 48±2 Bq.kg^{-1} and 345±15 to 545±24 Bq.kg^{-1} with mean values of 2.6 ±4.7, 39.6±7, 423.3±82.9 Bq.kg^{-1}, respectively. Maximum activity concentration of the ^{226}Ra was found in Sand-2 which was collected from the Wazirabad site whereas minimum concentration was observed in Sand-3 and 5 that were collected from the Jehlum city and Jatlaan. For ^{232}Th, maximum activity concentration was noted in the sand sample which was collected from the Khokhran Mirpur (Sand-4) and a minimum value was found in sample collected from the Jatlaan Mirpur (Sand -5). Minimum concentration value of ^{40}K was also noted in sand-5 whereas maximum value was observed in sand-2, collected from the Industrial Area of the Mirpur Azad Kashmir.

In gravel aggregates (see table 3), specific activities of ^{26}Ra, ^{232}Th and ^{40}K range from 10± 1 to 36±2 Bq kg^{-1} , 18±1to 29±2 Bq.kg^{-1} and 45±2 to 223±1Bq.kg^{-1} with mean values of 15.8±9.4, 24.2 ±3.8, 132.9±58.5 Bq.kg^{-1}, respectively. Maximum activity concentration of the ^{226}Ra was found in sample of gravel aggregates (A-5) collected from the Mangla site whereas minimum concentration was observed in A-6 that was collected from the Lehrdi Mirpur. Minimum concentration values of ^{232}Th and ^{40}K was found in A-6 and A-5 which were collected from Mangla and Lehrdi respectively, whereas maximum value was observed in A-4 which was collected from the Phalot Mirpur.

In brick samples (table 4), ^{226}Ra, ^{232}Th

Table 2. Measured values of the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied sand samples collected from the district Mirpur. R_{eq}, H_{ex}, H_{in}, I_γ, I_α, absorbed dose and Annual effective dose values are also given in this table.

Sample Code	^{226}Ra (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})	Req	H_{ex}	H_{in}	I_γ	I_α	Dair nGyh^{-1}	Annual effective dose mSv
Sand-1	25±1	43±2	417±18	115.68±6	0.32±0.01	0.39±0.02	0.44±0.02	0.13±0.01	57.1±3	0.28±0.015
Sand-2	29±1	44±2	517±23	128.11±6	0.36±0.02	0.43±0.02	0.49±0.02	0.15±0.01	63.7±3	0.31±0.015
Sand-3	18±1	43±2	393±17	107.00±5	0.30±0.01	0.35±0.02	0.41±0.02	0.09±0.01	53.1±2	0.26±0.010
Sand-4	27±1	48±2	545±24	133.79±7	0.37±0.02	0.44±0.02	0.51±0.02	0.14±0.01	66.7±3	0.33±0.015
Sand-5	18±1	30±2	345±15	85.05±4	0.24±0.01	0.28±0.02	0.33±0.02	0.09±0.01	42.4±2	0.21±0.010
Sand-6	21±1	33±2	361±16	93.46±5	0.26±0.01	0.32±0.02	0.36±0.02	0.11±0.01	46.3±2	0.23±0.010
GM± STDEV	22.6±4.7	39.6±7	423.3±82.9	109±19	0.30±0.05	0.36±0.06	0.42±0.07	0.11±0.02	54.2±9.6	0.27±0.05
average	23	40.17	429.7	110.5	0.31	0.37	0.42	0.12	54.9	0.27

Table 3. Measured values of the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied gravel aggregate samples collected from the district Mirpur. R_{eq}, H_{ex}, H_{in}, I_γ, I_α, absorbed dose and Annual effective dose values are also given in this table.

Sample Code	^{226}Ra (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})	Req	H_{ex}	H_{in}	I_γ	I_α	Dair nGyh^{-1}	Annual effective dose mSv
A-1	13±1	23±1	169±7	58.90±3	0.16±0.01	0.19±0.01	0.21±0.01	0.07±0.01	28.0±1	0.14±0.015
A-2	14±1	25±1	157±7	61.84±3	0.17±0.01	0.20±0.01	0.22±0.01	0.07±0.01	29.3±1	0.14±0.015
A-3	14±1	27±1	157±7	64.70±3	0.17±0.01	0.21±0.01	0.23±0.01	0.07±0.01	30.6±1	0.15±0.010
A-4	17±1	29±2	223±1	75.64±4	0.20±0.01	0.25±0.01	0.28±0.01	0.09±0.01	36.0±2	0.18±0.015
A-5	36±2	25±1	45±2	75.22±4	0.20±0.01	0.30±0.02	0.26±0.01	0.18±0.01	33.9±1	0.17±0.010
A-6	10±1	18±1	132±6	45.90±2	0.12±0.01	0.15±0.01	0.17±0.01	0.05±0.01	21.9±1	0.11±0.010
GM± STDEV	15.81±9.4	24.2±3.8	132.9±58.5	62.8±11.1	0.17±0.03	0. 21±0.05	0.23±0.04	0.08±0.05	29.6±4.9	0.15±0.02
average	17.3	24.5	147.17	63.7	0.17	0.22	0.23	0.09	29.9	0.15

and ^{40}K activities varied from 26±1 to 46±2 Bq kg^{-1}, 52±3 to 63±3 $Bqkg^{-1}$ and 554±2 to 683±3 $Bqkg^{-1}$ with mean values of 38.9±8.2, 59.4±3.9, 630.8±44.9 $Bqkg^{-1}$ respectively. Maximum value of specific activity concentration of ^{226}Ra was found B-3 which was collected from the M.A Mirpur site whereas minimum value was found in B-5 collected from the A.G Mirpur site. Minimum specific activity concentrations of ^{232}Th and ^{40}K were found in B-4 and B-5 which were collected from the A.A.P Mirpur and A.G Mirpur sites, respectively.

In marble samples (see, table 5), ^{226}Ra, ^{232}Th and ^{40}K activities varied from 18±1 to 41±3 Bq kg^{-1}, 18±1 to 33±2 $Bqkg^{-1}$ and 40±3to 82±4 $BqKg^{-1}$ with mean values of 27.8±8.9, 24.4±6, 59.3±16.4 $BqKg^{-1}$ respectively. Maximum value of specific activity concentration of ^{226}Ra was found M-4 which was collected from the M.A Mirpur site whereas minimum value was found in M-3 collected from the A.G Mirpur site. Minimum specific activity concentrations of ^{232}Th and ^{40}K were found in M-6 and M-5 and maximum were found in M-5 and M-1 respectively, which were collected from the A.A.P Mirpur and A.G Mirpur sites, respectively.

Assessment of radiological hazards

The measured specific activity concentrations were used to assess the radiological hazards associated with soil, sand, gravel aggregates, bricks and marbles of the studied area. As more than one radionuclide contributes towards the gamma doses (i.e. ^{226}Ra, ^{232}Th and ^{40}K), therefore radiological hazards are presented in terms of a single quantity called 'hazard index'.

Table 4. Measured values of the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied brick samples collected from the district Mirpur. R_{eq}, H_{ex}, H_{in}, I_γ, I_α, absorbed dose and Annual effective dose values are also given in this table.

Sample Code	^{226}Ra ($Bq.kg^{-1}$)	^{232}Th ($Bq.kg^{-1}$)	^{40}K ($Bq.kg^{-1}$)	Req	H_{ex}	H_{in}	I_γ	I_α	Dair $nGyh^{-1}$	Annual effective dose mSv
B-1	44±2	61±3	619±3	178.89±9	0.48±0.03	0.60±0.02	0.66±0.02	0.22±0.01	45.41±4	0.22±0.020
B-2	45±2	59±3	632±3	178.03±9	0.48±0.03	0.60±0.02	0.66±0.02	0.23±±0.01	86.77±3	0.43±0.015
B-3	46±2	62±3	639±3	183.86±9	0.50±0.03	0.62±0.02	0.68±0.02	0.23±±0.01	86.18±3	0.42±0.015
B-4	33±2	52±3	554±2	150.02±7	0.41±0.03	0.49±0.02	0.55±0.02	0.17±0.01	78.96±3	0.39±0.015
B-5	26±1	63±3	683±3	168.68±8	0.46±0.03	0.53±0.02	0.63±0.02	0.13±0.01	74.89±3	0.37±0.015
B-6	44±2	60±3	666±3	181.08±9	0.49±0.03	0.61±0.02	0.67±0.02	0.22±0.01	89.13±3	0.44±0.015
GM± STDEV	38.9±8.2	59.4±3.9	630.8±44.9	173 ±12.6	0.47±0.03	0.57±0.05	0.64±0.04	0.19±0.04	75.1±16.3	0.37±0.08
average	39.67	59.50	632.17	173.43	0.47	0.58	0.64	0.20	76.89	0.38

Table 5. Measured values of the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied Marble samples collected from the district Mirpur. R_{eq}, H_{ex}, H_{in}, I_γ, I_α, absorbed dose and Annual effective dose values are also given in this table.

Sample Code	^{226}Ra ($Bq.kg^{-1}$)	^{232}Th ($Bq.kg^{-1}$)	^{40}K ($Bq.kg^{-1}$)	Req	H_{ex}	H_{in}	I_γ	I_α	Dair $nGyh^{-1}$	Annual effective dose mSv
Marble-1	21±1	19±1	82±4	54.48±4	0.15±0.01	0.20±0.01	0.19±0.01	0.11±0.01	12.5±1	0.06±0.005
Marble-2	36±2	31±2	78±4	86.34±4	0.23±0.01	0.33±0.02	0.30±0.01	0.18±0.01	31.3±2	0.15±0.01
Marble-3	18±1	23±1	62±4	55.66±4	0.15±0.01	0.20±0.01	0.20±0.01	0.09±0.01	30.9±1	0.15±0.005
Marble-4	41±3	26±1	56±4	82.49±4	0.22±0.01	0.33±0.02	0.29±0.02	0.21±0.01	35.1±2	0.17±0.01
Marble-5	32±2	33±2	40±3	82.27±4	0.22±0.01	0.31±0.02	0.29±0.02	0.16±0.01	32.6±2	0.16±0.01
Marble-6	26±1	18±1	49±4	55.51±4	0.15±0.01	0.22±0.01	0.19±0.01	0.13±0.01	35.1±2	0.17±0.01
GM± STDEV	27.8±8.9	24.4±6	59.3±16.4	67.97±15.7	0.18±0.04	0.26±0.06	0.24± 0.05	0.14±0.04	28 ±8.6	0.14± 0.04
average	29	25	61.2	69.5	0.19	0.27	0.24	0.15	29.60	0.15

$$Ra_{eq} = A_{Ra} + (A_{Th} \times 1.43) + (A_k \times 0.077) \quad (5)$$

Where, A_{Ra}, A_{Th} and A_k are ^{226}Ra, ^{232}Th ^{40}K specific activity concentrations. From the radiological point of view, $Ra_{eq} \leq 370 BqKg^{-1}$. In the case when $Ra_{eq} \leq 370 BqKg^{-1}$ then external gamma dose will be less than 1.5 mGy y^{-1} (28, 29). Radium equivalent activity (Ra_{eq}) has been calculated for the studied soil and building material samples and results obtained are listed in tables 1-5. For soil samples Ra_{eq} varies from 71.82±4 to 197.10±9 $Bqkg^{-1}$, with mean value of 139.09±33.7 Bq kg^{-1}. For sand, gravel aggregates, bricks and marble samples Ra_{eq} activity varied from 85.05±4 to 128.11±6, 45.90±2 to 75.64±4, 150.02±7 and 54.48±4 to 86.34±4 Bq kg^{-1}, with mean values of 109±19, 62.8±11.1, 173±12.6 and 67.97±15.7 $Bqkg^{-1}$ respectively.

External hazard index

In order to assess the external radiological hazards from building materials, external hazard index (H_{ex}) is calculated using the following eexpression (30),

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

To limit the external gamma radiation dose from building materials below 1.5 mGy y^{-1} the external hazard index, H_{ex} should obey the following relation $H_{ex} \leq 1$ (29). External hazard indices for the soil, sand, gravel aggregate, bricks and marble samples varied from 0.19±0.01 to 0.53±0.03, 0.24±0.01 to 0.37±0.02, 0.12±0.01 to 0.20±0.01, 0.41±0.03 to 0.50±0.03 and 0.15±0.01 to 0.23±0.01 with mean values of 0.38±0.09, 0.30±0.05, 0.17±0.03, 0.47±0.03 and 0.18±0.04. The external hazard index for the studied samples is less than unity and therefore these building materials are safe to be used for construction.

Internal hazard index

The internal radiation hazards due to the inhalation of radon and its short-lived products are assessed using (30),

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

Like external hazard index, the construction materials would be safe if $H_{in} \leq 1$. Internal Hazard indices for the soil, sand, gravel aggregate, bricks and marble samples in current study varied from 0.23±0.01 to 0.66±0.03, 0.28±0.02 to 0.44±0.02, 0.15±0.01 to 0.30 ± 0.02, 0.49±0.02 to 0.62±0.02 and 0.20±0.01 to 0.33±0.02, with mean values of 0.45±0.11, 0.36±0.06, 0.21±0.05, 0.57±0.05 and 0.26±0.06 respectively. The internal hazard index for the studied samples of building materials is less than unity which indicates that the studied building materials are safe to be used for construction in the Mirpur.

Gamma index (Iγ)

European Commission has suggested a gamma activity concentration index, I_γ for defining radiation risk from excessive gamma exposure by the following relation (31, 32),

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (8)$$

Values of index $I_\gamma \leq 2$ corresponds to a dose rate criterion of 0.3 mSv y^{-1}, whereas $2 \leq I_\gamma \leq 6$ corresponds to a criterion of 1 $mSvy^{-1}$ (31, 33). Thus the material with $I\gamma > 6$ should be avoided to use as building material, since these values correspond to the dose rates higher than 1 mSv y^{-1} which is highest then recommended values (34). In the current study, I_γ was calculated using equation (8). The gamma index value ranged from 0.26±0.01 to 0.72±0.04, 0.33±0.02 to 0.51±0.02, 0.17±0.01 to 0.28±0.01, 0.55±0.02 to 0.68±0.02 and 0.19±0.01 to 0.30±0.01 for soil, sand, gravel aggregates, bricks and marbles samples, respectively, with mean values of 0.51±0.12, 0.42±0.07, 0.23±0.04, 0.64±0.04 and 0.24±0.05 respectively. All the current 'I_γ' values of the studied samples follow the criterion ($I_\gamma \leq 2$) therefore it may be concluded that the construction material used in the district Mirpur is safe and does not pose any significant health hazards.

Alpha index ($I_α$)

The excess alpha radiation due to the radon inhalation originating from the building materials is assessed through the alpha index ($I_α$) which is defined as follows [32].

$$I_{\gamma} = \frac{A_{Ra}}{200} \quad (9)$$

The recommended exemption and recommended upper levels of ^{226}Ra concentrations in building materials are 100 Bq kg^{-1} and 200 Bq kg^{-1} [35]. When the ^{226}Ra activity concentration of building materials exceeds the value of 200 Bq.kg^{-1}, it is possible that radon exhalation from this material may cause indoor radon concentration greater than 200 Bq.m^{-3}. On the other hand, if ^{226}Ra concentration is less than 100 Bq.kg^{-1}, than resulting indoor radon concentration is less than 200 Bq.m^{-3} [35]. These considerations are reflected in the alpha index. The recommended limit concentration of ^{226}Ra is 200 Bq.kg^{-1}, for which $I_α = 1$. Using equation (9), alpha index was calculated. The values of $I_α$ ranged from 0.07±0.01 to 0.23±0.01, 0.09±±0.01 to 0.15±0.01, 0.05±0.01 to 0.18±0.01, 0.13±0.01 to 0.23±±0.01 and 0.09±0.01 to 0.21±0.01 for soil, sand, gravel aggregates, bricks and marbles samples with mean values of 0.14±0.04, 0.11±0.02, 0.08±0.05, 0.19±0.04 and 0.14±0.04, respectively. These observed values are less than unity showing that construction materials are safe from the point of view of environmental radiation hazards.

Radiation doses

In order to calculate the dose rate in air from the samples collected from the area under study, the following relation was used [36].

$$\dot{D} = \sum_{x} A_x \times C_x \quad (10)$$

Where A_x(Bq.kg^{-1}) is the mean activity of ^{226}Ra, ^{232}Th and ^{40}K and C_x (nGyh^{-1} per Bq kg^{-1}) is the corresponding dose conversion factor. The dose conversion factors used in the calculation for ^{226}Ra, ^{232}Th and ^{40}K were 0.427, 0.662 and 0.043, respectively [36].

As may be seen from table 1-6, absorbed dose rates for soil, sand, gravel aggregates, bricks and marbles varies from 34.7±2 to 94.8±5, 42.4±2to 66.7±3, 21.9±1 to 36.0±2, 45.41±4 to 89.13±3 and 12.5±1 to 35.1±2 nGyh^{-1} with mean values 66.9±16.04, 54.2±9.6, 29.6±4.9, 75.1±16.3 and 28±8.6 nGyh^{-1}.

The annual effective dose equivalent to be received by the public due to the activity

Table 6. Comparison of mean radium equivalent activity observed in the current study with some of the data available in the literature (Bq kg^{-1}).

Country	Soil	Sand	Gravel /Aggregates	Clay Bricks	Marble/ limestone	Reference
Algeria	-	28	58	130	37	(13)
Australia	-	70	115	-	-	(30)
China	-	96	82	-	-	*(24)*
Germany	-	59	322	-	-	(29)
India	-	170.8	-	151.7	-	(22)
Pakistan Punjab	149	91	-	106	82	*(38)*
Pakistan (Punjab)	141	-	-	-	-	(25)
Punjab	158.5	-	-	-	-	(23)
Punjab	122	-	-	-	-	(14)
Isl/Rwp	211	-	-	-	-	(34)
Lahore	252	-	-	-	-	(34)
MirPur, Azad Kashmir	143±7	113±5	45±2	174±8	69±4	Present study

in soil and building materials has been calculated using the following relation [36].

$$\dot{E} = T \times Q \times \dot{D} \times O_f \times 10^{-6} \qquad (11)$$

Where the value of Q is 0.7 SvGy^{-1} y^{-1} for environmental exposure to gamma rays of moderate energy, T is time in hours in one year, i.e., 8760h, O_f is the occupancy factor (0.8), and *"D"* is the dose rate given in equation (3). The mean annual effective dose equivalent in the six districts of Punjab, as calculated by equation (4), was about 0.34 mSvy^{-1}, which is within the permissible dose equivalent limit (i.e., 1 mSvy^{-1}) [37]. Having determined the mean annual effective dose equivalent,

The annual effective dose (see table 1-6) for soil, sand, gravel aggregates, bricks and marbles varies from 0.170±0.010 to 0.47±0.025, 0.21±0.01 to 0.33±0.015, 0.11±0.010 to 0.18±0.015, 0.22±0.020 to 0.44±0.015 and 0.06±0.005 to 0.17±0.010 mSv with mean values 0.33±0.08, 0.27±0.05, 0.15±0.02, 0.37±0.08 and 0.14±0.04 mSv respectively.

Figure 2 gives geometric mean (G.M) values of specific activities due to ^{226}Ra, ^{232}Th, ^{40}K and $Ra_{eq.}$ As may be seen from figure 2, bricks are major source of activities followed by soil and sand samples. In table 6, mean radium equivalent activities of present study have been compared with those published by the other groups. Current values of radium equivalent, specific activity for soil, sand, gravel aggregates, bricks and marble samples are greater than the values reported for some countries like Algeria, Australia, and china. For soil samples, radium equivalent activity observed in current study is less than the values reported for other parts of the country like Islamabad/Rawalpindi, Lahore and other cities of the Punjab. From table 1-6, it may be seen that activities due to ^{226}Ra, ^{232}Th and ^{40}K for the sample collected from district Mirpur of Azad Kashmir are within the world range reported by UNSCEAR 2000 (for ^{226}Ra 17-60 Bq kg^{-1}, for ^{232}Th 11-64 Bq kg^{-1} and for ^{40}K 140-850 Bq kg^{-1}) .

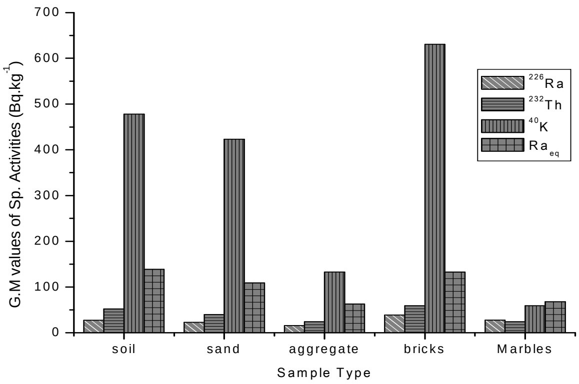

Figure 2. Variations in geometric mean of specific activities due to ^{226}Ra, ^{232}Th, ^{40}K and Ra_{eq}.

CONCLUSION

Specific activities of ^{226}Ra, ^{232}Th and ^{40}K in soil and building materials collected from different sites of the district Mirpur have been measured using HPGe based gamma spectroscopy technique. The radium equivalent activity, external and internal hazard indices, gamma and alpha indices, terrestrial absorbed dose and annual effective dose have been determined to assess the radiological hazards from building materials used in studied area.

Radium equivalent activity, all the hazard indices and Mean annual effective dose have been found to be within recommended limits. In view of the current study, studied soil and building material would not pose any significant source of radiation hazard if used in the construction of buildings.

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