DISTRIBUTION OF RADIONUCLIDES IN SURFACE SOIL AND BOTTOM SEDIMENT IN THE DISTRICT OF JESSORE, BANGLADESH AND EVALUATION OF RADIATION HAZARD.

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ABSTRACT

This paper presents the first reports on the natural and anthropogenic radionuclides in soil and sediment of Jessore, a south-western district of Bangladesh. Surface soil and freshwater sediment were collected from in and around some major water-bodies of this district. To assess the radiological hazard of the natural radioactivity, the radium equivalent activity, the absorbed dose rate, and the external and internal hazard indices were calculated. In the soil and sediment in general, the activity concentration of ^{232}Th was found to be higher than that of ^{226}Ra, while that of ^{40}K markedly exceeds the values of both ^{226}Ra and ^{232}Th. The average activities of ^{226}Ra and ^{232}Th in this area were found to be higher than the world average. There was no activity due to fallout (^{137}Cs) in this area. The radium equivalent activity and the absorbed dose rate due to the natural radionuclides were found to be respectively lower and higher than the world average. The external and internal hazard indices were found to be well below the hazard limit of unity. Our results compare fairly well with other published results.

Key-words : Soil, Sediment, Natural lake, Radioactivity, Dose rate

1. INTRODUCTION

Naturally occurring primordial radionuclides have been present in the environment since the formation of the earth. Predominant part of the radioactivity of soil and sediment derives from the decay of the primordial radionuclides ^{238}U, ^{235}U, ^{232}Th, ^{87}Rb and ^{40}K and the numerous decay products of the first three of them. Significant amount of man-made radionuclides ^{137}Cs and ^{90}Sr may also present in the soil and sediment as a result of testing of nuclear weapons in the atmosphere, accidents such as the Chernobyl accident and the routine discharge of radionuclides from nuclear installations. The contribution of other nuclides to the total activity is negligible [(1)]. Once present in the environment, these radionuclides, whether natural or artificial, are available for uptake by plants and animals and so make their way into the food chain.

Because of natural and artificial processes, radionuclides may accumulate and be concentrated in selected areas of the environment. Regional and local variation in the distribution and availability of natural radioactive materials for ingestion and inhalation are related to ancient geological processes and a combination of contemporary geological stress, atmospheric conditions, and intervention by man [(2)]. The natural radioactivity of soil and sediment depends on their formation and transport processes that were involved since soil and sediment formation; chemical and biochemical interactions influence the distribution patterns of Uranium, Thorium and their decay products.

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Studies on radiation levels and radionuclides distributions in Jessore have not been carried out so far. The aim of this study was to determine natural (^{226}Ra, ^{232}Th, ^{40}K) and artificial (^{137}Cs) radioactivity levels in soils and sediments collected from different areas of Jessore. Also, the radium equivalent activity (Ra_{eq}), the absorbed dose rate, and external and internal radiation hazard indices which will be defined later have been calculated and compared with the results in literatures.

2. EXPERIMENTALS

Sample collection

The Jessore district, situated in the south-western region of Bangladesh, was surveyed to collect the soil and sediment samples from different locations of the region. The locations are shown in the Fig.1. Soil sample was collected (at a depth of 0-5 cm.) from the area adjacent to the water-bodies from which sediment sample was collected. The collected soil samples represent the major soil type of the region. All the locations selected for soil sample collection were open, not prone to flooding or other natural disturbances and were not affected by human activities during the recent decades which represent undisturbed soils. All the samples were collected at 5 cm depth from the soil-surface. Each of the samples was weighed by 500 gm. The samples were transported in dried acetone-cleaned polyethylene bags with sample codes.

Bottom sediment samples were collected from 23 different water-bodies (21 baors, one beel and one pond) of the district of Jessore in a period of low water levels during the dry season, January and April 2007. Sediments were taken from the middle of the water bodies so that undisturbed sediment samples could be taken. One sediment sample from each site was taken, each about 1 kg wet weight placed in polyethylene bags with sample code and transferred to the laboratory.

Sample preparation

At the lab, the collected samples were transferred from the polyethylene bags to the acetone-cleaned stainless steel bucket and dried in an oven at 100-105 ^{0}C until a constant weight was achieved. Each of the dried samples was grounded to fine powder in an agate motor separately. The powdered soil and sediment samples were then sieved using a fine-aperture mesh screen (mesh size 2 mm) in order to remove extraneous items like plant materials, roots, pebbles etc. and to obtain a fine-grained sample that would present a uniform matrix to the detector. The grounded samples were stored in separate polyethylene packets as stock samples.

Finally, each of the samples was transferred to cylindrical plastic-container. The containers were approximately of equal size and shape (i.e., diameter 6.5 cm and height 7.5 cm). The net weight of each sample was calculated using a micrometer. The mass of the samples varied because of the varying density of the sample material (Table-1). The containers were then sealed tightly, wrapped with thick vinyl tapes around their screw necks. The samples were stored for at least four weeks to reach secular equilibrium between the ^{238}U and ^{232}Th series and their respective progenies to get ready for measurements [2].

Measurement procedures

Measurements were carried out on these samples using a γ-ray spectrometer comprising p-type co-axial intrinsic HPGe detector of active volume 132 cc supplied by Oxford Instruments Inc. Nuclear Measurement Group (Model No. CPVDS 30-30185 and Serial No. 2604) with relative efficiencies of 30% and resolution (FWHM) of 1.83 keV for the 1332 keV γ-ray energy of ^{60}Co. The detector was coupled with PC based multi-channel analyzer (PCMCA card: TRUMP-PCI-8K) and the gamma-ray spectral analysis was based on a window based software (MAESTRO-32, ver. 5.30 (A65-B32) supplied by the ORTEC, USA) which matched gamma energies at various energy levels to a library of possible isotopes.

Direct determination of ^{226}Ra and ^{232}Th in the samples without any chemical treatment using semiconductor γ-ray spectrometer is very hard because they do not emit any intensive γ-rays (lines) of their own. But they have several progenies which have more intensive lines and activities equal to their parents in the state of secular equilibrium. As a result, the measurements of the radionuclides relied on the detecting emissions from their progenies.

The radioactivity concentration of ^{226}Ra was determined from γ-ray energies of its daughters ^{214}Pb (351.92 & 295.21 keV) and ^{214}Bi (609.31, 1120.30 & 1764.50 keV) and the ^{232}Th was determined from γ-ray energies of its daughters ^{212}Pb (238.63 keV), ^{208}Tl (583.14 & 510.84 keV) and ^{228}Ac (911.07 & 969.11 keV). The radioactivity concentrations of ^{40}K and ^{137}Cs were determined from their γ-ray energy of 1460.80 keV and 662 keV respectively.

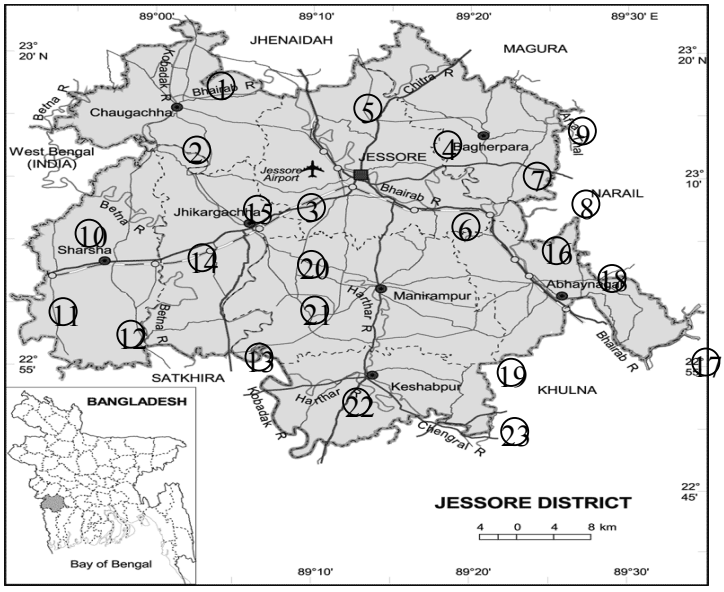

Fig 1. Location of sampling stations.

Table. 1.

Sites from which surface soil and bottom sediment samples were taken

Sample	**Site**	Sample weight (g)	
		soil	sediment
1	***Marjat Baor, Chaugachha***	368.5	240.0
2	Ber-Gobindapur Baor, Chaugachha	331.8	334.7
3	Bookbhara Baor, Jessore Sadar	389.3	379.0
4	Ghurulia Baor, Jessore Sadar	323.5	312.2
5	Laukhali Baor, Jessore Sadar	361.0	284.0
6	Khanika picnic-spot pond, Jessore Sadar	362.0	358.0
7	Habullae Baor, Bagharpara	341.3	266.2
8	Radhanagar Baor, Bagharpara	408.0	329.5
9	Manikdi Baor, Bagharpara	305.0	308.0
10	Bahadurpur Baor, Sharsha	377.0	361.5
11	Rajagonj Baor, Sharsha	391.0	305.8
12	Mohishakura Baor, Sharsha	394.0	313.0
13	Ujjajpur Baor,Jhikargachha	351.3	346.0
14	Srirampur Baor, Jhikargachha	382.0	287.5
15	Bodkhan Baor, Jhikargachha	346.0	343.0
16	Prembag Baor, Abhainagar	367.8	237.0
17	Nawli Beel, Abhainagar	313.0	300.0
18	Purakhali Baor, Abhainagar	270.0	269.5
19	Nehalpur Beel, Monirampur	370.8	251.8
20	Hariharnagar Baor, Monirampur	333.0	285.0
21	Khedapara Baor, Monirampur	357.0	308.5
22	Mosina Baor, Keshabpur	346.4	297.0
23	Garalia Beel, Keshabpur	303.0	314.0

The efficiency calibration of the detector was performed by using mixed standard sources ^{133}Ba and ^{137}Cs supplied by the Amersham International, England, sample code no. QCY B41 mixed with 400 g of analar grade Al_2O_3 so as to make composite reference sources comprising of various gamma energies in a simulated crushed sample matrix. Each sample was counted for 5000 sec. Prior of sample counting, two background counts were normally taken twice during week ends for 5000 sec each and on average of this background was then subtracted from the samples counted during that week.

Theoretical calculations

The activity concentrations

The activity concentrations of the radionuclides in the measured samples were computed using the following relation [(3)],

$$A_s(BqKg^{-1}) = \frac{C_a}{\varepsilon P_\gamma M_s} \qquad \text{----------(1)}$$

where C_a is the net gamma counting rate (counts per second), ε the detector efficiency of the specific γ-ray, P_γ the transition probability of gamma decay and M_s is the mass of the sample (kg).

Radium equivalent activity

For the purpose of comparing the radiological effect or activity of materials that contain ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them, a common index termed the radium equivalent activity (Ra_{eq}) is used. This activity index provides a useful guideline in regulating the safety standards on radiation protection for the general public residing in the area under investigation. The Ra_{eq} index represents a weighted sum of activities of the above mentioned natural radionuclides and is based on the estimation that 1 $Bqkg^{-1}$ of ^{226}Ra, 0.7 $Bqkg^{-1}$ of ^{232}Th, and 13$Bqkg^{-1}$ of ^{40}K produce the same gamma radiation dose rates. The index is given as [4] :

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad \text{----------(2)}$$

where A_{Ra}, A_{Th} and A_k are the average activity concentration in the sample in $Bqkg^{-1}$ of ^{226}Ra, ^{232}Th, and ^{40}K respectively.

The absorbed dose rate

The absorbed dose rate in air at average gonad height of one meter above the surface of ground due to the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K was estimated using formula given in UNSCEAR, 1988 [4] as under :

$$D = [0.427A_{Ra} + 0.662A_{Th} + 0.0432A_K]\,nGyh^{-1} \qquad \text{----------(3)}$$

where A_{Ra}, A_{Th} and A_k have the same meaning as in Equation 2.

External and Internal Hazard indices

The soils and sediments are used for making earthen huts, bricks and pottery materials and, hence, the external radiation hazard index, H_{ex} and internal radiation hazard index, H_{in} were calculated using the following relations [2].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \qquad \text{----------(4)}$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad \text{----------(5)}$$

where A_{Ra}, A_{Th} and A_k have the same meaning as in Equation 2.

Table. 2.
Radioactivity concentrations of radionuclides as well as the calculated Ra equivalent activity, absorbed dose rate, external hazard index and internal hazard index in soil and sediment samples across the district of Jessore.

Sam. No	Types of sample	Activity concentration(Bqkg $^{-1}$)				Ra_{eq} (Bqkg $^{-1}$)	Dose Rate D (nGyh^{-1})	H_{ex}	H_{in}
		^{226}Ra	^{232}Th	^{40}K	^{137}Cs				
1	soil	43 ± 2	54 ± 3	413 ± 32	-	152±9	72±4	0.41±0.02	0.53±0.03
	sediment	**23±2**	**20±5**	**254±43**	-	**71±12**	**34±6**	**0.19±0.03**	**0.25±0.04**
2	soil	46 ± 2	43 ±4	487 ± 36	-	145±10	69±5	0.39±0.03	0.52±0.03
	sediment	25±2	36±3	391±56	-	107±11	51±5	0.29±0.03	0.36±0.03
3	soil	56± 2	63± 4	424± 31	-	179±12	84±5	0.48±0.03	0.63±0.03
	sediment	41±2	45±5	426±31	-	138±12	66±6	0.37±0.03	0.48±0.04
4	soil	47 ±2	52 ± 4	542 ± 37	-	163±11	78±5	0.44±0.03	0.57±0.03
	sediment	44±2	43± 8	470±38	-	142±16	68±8	0.38±0.04	0.50±0.05
5	soil	51 ± 2	64± 4	441 ± 33	-	177±10	83±5	0.48±0.03	0.61±0.03
	sediment	56 ± 2	57 ±18	548±42	-	180± 31	85±15	0.49±0.08	0.64±0.09
6	soil	49 ± 2	58 ± 4	464 ± 32	-	168 ± 10	79±5	0.45±0.03	0.59±0.03
	sediment	42 ±2	32±12	422 ± 33	-	120±22	57±10	0.25±0.06	0.44±0.06
7	soil	44 ± 2	48 ± 4	424 ± 34	-	145±10	69±5	0.39±0.03	0.51±0.03
	sediment	35±2	37±18	411±42	-	120±31	57±15	0.32±0.08	0.42±0.09
8	soil	47± 2	53 ± 4	428 ± 29	-	156±10	74±5	0.42±0.03	0.55±0.03
	sediment	35 ± 2	47 ±4	410±35	-	134±10	64±5	0.36±0.03	0.46±0.03
9	soil	55 ± 2	53 ± 4	611 ± 40	-	178±11	85±5	0.48±0.03	0.63±0.03
	sediment	61±2	**85±7**	**986±43**	-	**259±15**	**125±7**	**0.70±0.04**	**0.86±0.05**
10	soil	44 ± 2	**33 ± 6**	500 ± 51	-	**130±15**	**62±7**	**0.35±0.04**	0.47±0.04
	sediment	39±2	34±11	405±52	-	119±22	57±10	0.32±0.06	0.43±0.06
11	soil	47 ± 2	53 ± 4	424 ± 31	-	155±10	73±5	0.42±0.03	0.55±0.03
	sediment	55±2	39±7	497±39	-	149±15	71±7	0.40±0.04	0.55±0.05
12	soil	55 ± 2	**70 ± 4**	**345 ± 29**	-	182±10	85±5	0.49±0.03	0.64±0.03
	sediment	49±2	65±16	597±39	-	188±28	90±13	0.51±0.07	0.64±0.08
13	soil	50 ± 2	46 ± 4	397 ± 33	-	146±10	69±5	0.40±0.03	0.53±0.03
	sediment	36± 2	43±5	393±33	-	128±12	61±6	0.35±0.03	0.44±0.04
14	soil	44 ± 2	55 ± 4	438 ± 31	-	156±10	74±5	0.42±0.03	0.54±0.03
	sediment	32± 2	49±10	666±42	-	153±19	75±9	0.41±0.05	0.50±0.06
15	soil	61 ± 2	56 ± 4	495 ± 35	-	179±10	84±5	0.48±0.03	0.65±0.03
	sediment	32± 2	57±15	458±34	-	149±26	71±12	0.40±0.07	0.49±0.08
16	soil	52 ± 2	49 ± 3	392 ± 32	-	152±9	72±4	0.41±0.02	0.55±0.03
	sediment	36±2	55±9	513±48	-	154±19	74±9	0.42±0.05	0.51±0.06
17	soil	65± 2	56 ± 4	614 ± 38	-	192±11	91±8	0.52±0.03	0.70±0.03
	sediment	50±2	63±2	701±40	-	194±8	93±4	0.52±0.02	0.66±0.03
18	soil	**67± 2**	64 ± 5	**674 ± 45**	-	**210±13**	**100±6**	**0.57±0.03**	**0.75±0.04**
	sediment	37±2	38±9	457±43	-	126±18	61±7	0.34±0.05	0.44±0.05
19	soil	**28± 2**	45 ± 6	514± 52	-	132±15	64±7	0.36±0.04	**0.43±0.04**
	sediment	58±3	50±19	515±45	-	169±34	80±16	0.46±0.09	0.61±0.10
20	soil	47 ± 2	50 ± 4	481 ± 36	-	156±10	74±5	0.42±0.03	0.55±0.03
	sediment	47±2	42±14	389±39	-	137±25	65±12	0.37±0.07	0.50±0.07
21	soil	45 ± 2	70 ± 4	489 ± 33	-	183±10	87±5	0.49±0.03	0.62±0.03
	sediment	53±2	68±11	493±37	-	188±21	89±10	0.51±0.06	0.65±0.06
22	soil	36 ± 2	45 ± 6	556 ± 58	-	143±15	69±7	0.39±0.04	0.48±0.04
	sediment	41± 2	40± 9	531±40	-	139±18	67±9	0.38±0.05	0.49±0.05
23	soil	30 ± 2	48 ± 3	518 ± 39	-	139±9	67±4	0.37±0.03	0.46±0.03

	sediment	**62±2**	55±8	629±39	-	189±16	90±8	0.51±0.04	0.68±0.05
Aver-age ±1σ	soil	48 ±9	53± 9	481± 78	-	161± 20	77 ± 9	0.44±0.05	0.57±0.07
	sediment	43±11	48 ± 14	503 ± 143	-	150 ± 37	72 ± 18	0.40±0.10	0.52±0.13

(± values represent counting error for individual measurement and standard deviation for average. The maximum and minimum values are given in bold face)

3. RESULTS AND DISCUSSION

Table-2 presents the calculated activity concentrations of radionuclides obtained from gamma spectrometry measurements for 23 soil and 23 sediment samples collected from different areas of the district of Jessore, Bangladesh. Also shown are the derived radium equivalent activity, the absorbed dose rate, and external and internal radiation hazard indices due to activity concentration of the natural radionuclides measured. Three major natural gamma radiation sources were identified. Radium-226 was the precursor of most of the γ-emitting radionuclide identified in the U decay series. Thorium-232 was the likely precursor of the isotopes identified in the Th decay series. Potassium-40 which accounted for most of the activity being the third source [5].

Although it is unlikely that two samples from different locations have similar radioactivity yet the values found in this work are comparable to the results reported by others. It should be noted that the values given in the Table-3 and Table-4 are not the representative values for the respective countries but for the locations from where the samples have been collected.

For **^{226}Ra** activity concentration, each value was obtained from the 351.92 keV photo-peaks of ^{214}Pb. The results for soil ranged from 28±2 to 67±2 Bqkg^{-1} with an average of 48± 9 Bqkg^{-1} and that for sediment ranged from 23±2 to 62±2 with an average of 43±11 Bqkg^{-1}. For the **^{232}Th** activity concentration, each value was an average of three values obtained from 238.63keV photo-peaks of ^{212}Pb, 911.07 and 969.11 keV photo-peaks of ^{228}Ac. The results for soil ranged from 33±6 to 70±4 Bqkg^{-1} with an average of 53±9 Bqkg^{-1} and that for sediment ranged from 20±5 to 85±7 with an average of 48±14 Bqkg^{-1}. The activity concentration of **^{40}K** was obtained from its photo-peak of 1460.80 keV. The results for soil ranged from 345±29 to 674±45 Bqkg^{-1} with the average value of 481± 78 Bqkg^{-1} and that for sediment ranged from 254±43 to 986±43 with an average of 503±143 Bqkg^{-1}. The errors quoted represent the counting error for individual measurements and standard deviation for means.

Fig. 2 - 5 show that the activity concentration of thorium is higher than radium, which is evident from the fact that thorium is 1.5 times higher than that of Uranium in earth's crust[13]. It is also observed that the measured activity concentration of ^{40}K exceeds markedly the values of both Radium and Thorium, as it is the most abundant radioactive element under consideration. Moreover the excessive use of the Potassium containing fertilizers in the area adjacent to the sampling sites may contribute to the higher values of ^{40}K activity. In the present study, activity concentrations of ^{226}Ra and ^{232}Th in soil and sediment are comparable with the reported values in Table-3, especially with the different regions of Bangladesh [6-9, 17]. The activity concentrations of ^{40}K are comparable with the other values reported in Table 3. Moreover, our obtained values fall within the range of corresponding world values and other published results mentioned in Table-3. The world average activity concentration of ^{226}Ra is 40 Bqkg $^{-1}$ with ranges of 15 – 50 Bqkg $^{-1}$, ^{232}Th is 40 Bqkg $^{-1}$ with ranges of 7 – 50 Bqkg $^{-1}$ and ^{40}K is 580 Bqkg $^{-1}$ with ranges of 100 – 700 Bqkg $^{-1}$[1, 4].

The fission product (^{137}Cs)

The manmade fission product residue ^{137}Cs, which would come down to this part of the earth from the atmosphere following the nuclear power plant accident at Chernobyl on

26 April 1986 and other previous test of nuclear devices around the world, was considered in this study to obtain an estimate of fallout in Jessore. But no detectable activity of ^{137}Cs was observed in the soil and sediment samples under study. It implies, therefore, that there is no activity due to fallout in the area of the district of Jessore.

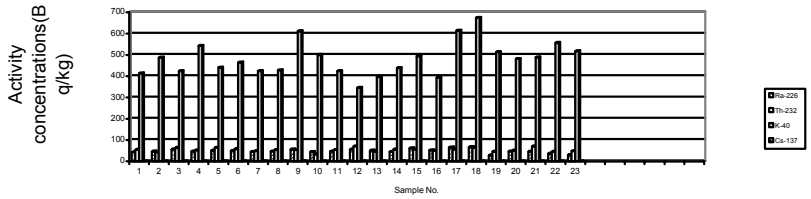

Fig. 2. Activity concentrations in the soil samples (Bq/kg)

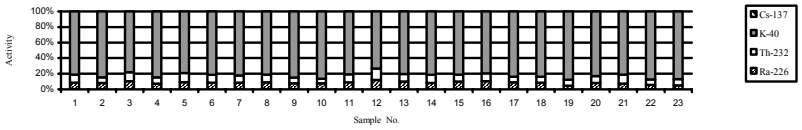

Fig. 3. Fractional contribution of the radionuclides present in our soli samples

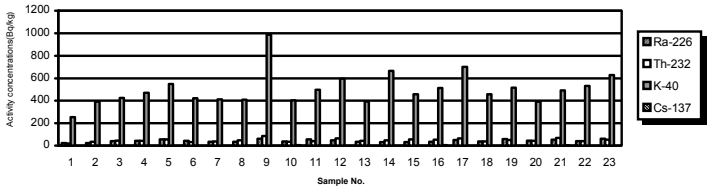

Fig. 4. Activity concentrations in the sediment samples (Bq/kg)

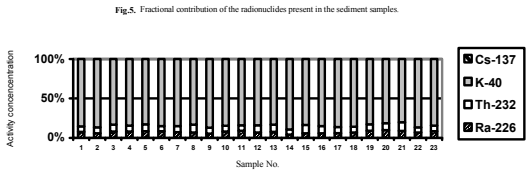

Fig. 5. Fractional contribution of the radionuclides present in the sediment samples (Bz/kg)

Table. 3.
Comparison of Radioactivity Level of the Soil and sediment Samples of Different Countries with that of the Present Work

Country	Type of Sample	Activity in Bqkg^{-1}			
		^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Chittagong (Bangladesh)[6]	Soil	34.6	60	438	1.08
Pabna (Bangladesh)[7]	Soil	33	47	449	4
Dhaka (Bangladesh) [8]	Soil	33	55	574	7
Nine southern districts (Bangladesh)[9]	soil	42	81	833	2.08
Peshawar (Pakistan)[10]	Soil (brick)	65	84	646	-
Louisiana (USA)[5]	Soil	43-95	50-190	43-729	5-58
Zacatecas (Mexico)[3]	Soil	23	19	530	-
All India average[11]	Soil	31	63	394	-
Jessore (Bangladesh) [Present study]	**Soil**	**48.32 (28 - 67)**	**53.34 (33 - 70)**	**481.35 (345 - 674)**	**-**
Worldwide average[1]		**40(15-50)**	**40(7-50)**	**580(100-700)**	**-**
Vojvodina(Serbia and Montenegro)[12]	Sediment	30	49	520	45
Danube [13]	Sediment	32	36	445	28
USA(Louisiana) [5]	Sediment	45-69	10-17	276-686	1-43
Lake Nasser(Egypt)[14]	Sediment	21(4-48)	23(8-50)	155(16-487)	-
Grliska Lake(Serbia) [15]	Sediment	7.9-12.2	18-31.3	271-456	14.5-31.9
French [16]	sediment	9-62	16-55	120-1026	-
Chittagong (Bangladesh) [6]	Sediment(Karnaph-uli river)	35.9(18.4-85.2)	65.5(50.8-88.4)	272(217-320)	2.2 (1.68-2.7)
	Sediment(Shango river)	27.8(24-31.9)	57.5(52.4-61.7)	255(212-292)	2.1 (1.6-2.6)
Bay of Bengal (Bangladesh) [17]	Sediment	18-101	-	138-1318	-
Jessore (Bangladesh) [Present study]	**Sediment**	**43 (23 - 62)**	**48 (20 - 85)**	**503 (254 - 986)**	**-**

Radium equivalent activity, Ra_{eq}

Calculated data of Ra_{eq} is presented in column 7 of Table 2. The Ra_{eq} for soil varied in the range 130±15 - 210±13 Bqkg^{-1} with the average value of 161±20 Bqkg^{-1} and that for sediment varied in the range 71±12 - 259±15 with an average value of 150±37 Bqkg^{-1}. Those are far below the allowable limit (370 Bqkg^{-1}) as recommended by the IAEA [1,2,4].

The absorbed dose rate

In the present study the dose rate due to ^{226}Ra, ^{232}Th, and ^{40}K in soil samples varied from 62±7 to100±6 nGyh^{-1}with an average of 77±9 nGyh^{-1} and that for sediment varied from 34±6 to 125±7 with an average value of 72±18 nGyh^{-1}. Those are comparable with the world average value of 55 nGyh^{-1}[4].

External and Internal Hazard Index

The external hazard index (H_{ex}) due to natural gamma radiation was calculated using the eq.(4) and the values are shown in column 9 of Table 2. The H_{ex} value for soil in the study area ranged from 0.35±0.04 to 0.57±0.03 with the average value of 0.44±0.05, and that for sediment ranged from 0.19±0.03 to 0.70±0.04 with the average value of 0.4±0.1. The calculated H_{ex} values for all samples should be lower than unity, which do not cause any harm to the population in all regions under investigation. All values of H_{ex} in the present work are less than unity.

There is also a radiation hazard threat to respiratory organs due to the ^{222}Rn, decay product of ^{226}Ra, and its short-lived decay products. To account for this the maximum permissible concentration for radium must be reduced to half of the normal limit [2]. Considering this limit, the internal hazard index, H_{in} was calculated and is shown in the last column of Table 2. The H_{in} for soil is found to range from 0.43±0.04 to 0.75±0.04 with the average value of 0.57±0.07 and for sediment it was found to range from 0.25±0.04 to 0.86±0.05 with the average value of 0.52±0.13.

Table. 4.
Comparison of absorbed dose rate at one meter above the ground surface obtained in our study with that of others of the world

Country	Year	*No of samples*	Absorbed dose rate in $nGyh^{-1}$	Range $nGyh^{-1}$	Method of analysis
China [4]	1972	26	69	-	Analysis of soil using gamma spectrometry
Romania [4]	1979	2372	81	32-210	Analysis of soil using gamma spectrometry
Nigeria [18]	2000	20	128	5-186	Analysis of rocks using gamma spectrometry
Bangladesh (six districts) [19]	2003	13	77	59-103	Analysis of soil using gamma spectrometry
Chittagong (Bangladesh) [6]	1999	24	75	42-120	Analysis of soil using gamma spectrometry
India (Kotagiri) [20]	2002	39	95.2	-	Analysis of soil using gamma spectrometry
World average [4]			55	30-70	
Jessore, Bangladesh (Present study)	2007	23	77	62 - 100	Analysis of soil using gamma spectrometry

Table 3 and Table 4 show the comparative study of the present work with others of the world. However, slight variation in the radioactivity content in soil and sediment may be observed with different locations worldwide mainly due to soil type, formation and transport process involved. This may be the reason for the variation observed in our results as compared to those of others.

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