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Effect of Fukushima Accident on Tourists Based Coastal Belts of Chittagong City, Bangladesh

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Abstract

This research work was aimed to obtain the radioactive exposure of naturally occurring and anthropogenic radioactive materials in sediment samples from the coastal belts of Chittagong city due to the Fukushima nuclear accident. The activity concentration, absorbed outdoor and indoor dose rates, annual effective dose rates and the radiation hazard indices from these samples were calculated. The correlation coefficient and Chi-square value per degree of freedom were also determined. A strong correlation between radium equivalent activity and activity of ^{232}Th was obtained in the Bay of Bengal. However, a very poor correlation was observed for radium equivalent activity and activity of ^{40}K in both the study areas. The Chi-square value per degree of freedom (χ_R^2) for ^{226}Ra, ^{232}Th and ^{40}K were respectively 70.244, 77.168 and 1.87 for the Karnaphuli River samples and 38.091, 62.023 and 2.06 for the Bay of Bengal samples. No artificial radionuclide was detected in the samples measured from the study areas. No radiation threat level is obtained on the study areas due to the nuclear explosion at Fukushima.

Keywords: *Fukushima accident; Radiation exposure; Correlation; Chi-square values.*

চট্টগ্রাম নগর সংলগ্ন উপকূলীয় এলাকার পাললিক নমুনাসমূহে ফুকুশিমা পারমাণবিক দূর্ঘটনা জনিত কারণে প্রাকৃতিক ও কৃত্রিম ভাবে সৃষ্ট তেজস্ক্রিয় পদার্থ থেকে সম্পাত বের করার উদ্দেশ্যে এ গবেষণা কর্মটি সম্পাদন করা হয়েছিল। এ নমুনাসমূহে সক্রিয়তা ঘনত্ব, শোষিত গৃহস্থিত ও বহিরঙ্গন দাগহারসমূহ, বার্ষিক কার্যকর দাগহারসমূহ এবং বিকিরণ বিপদ সূচক হিসেব করা হয়েছিল। সহ-সম্বন্ধাঙ্ক এবং প্রতি স্বাধীনতার মাত্রায় কাই-বর্গ মানও বের করা হয়েছিল। বঙ্গোপসাগরে রেডিয়াম তুল্য সক্রিয়তা এবং ^{232}Th -এর সক্রিয়তার মাঝে সুদৃঢ় সহ-সম্বন্ধ পাওয়া গিয়েছিল। সে যাই হোক, উভয় পর্যেষণা এলাকাতেই রেডিয়াম তুল্য সক্রিয়তা এবং ^{40}K -এর সক্রিয়তার মাঝে খুব দূর্বল সহ-সম্বন্ধ পাওয়া গিয়েছিল। প্রতি স্বাধীনতার মাত্রায় কাই-বর্গ (χ_R^2) মান ^{226}Ra, ^{232}Th এবং ^{40}K -এর জন্য যথাক্রমে কর্ণফুলী নদীর নমুনাসমূহের জন্য ৭০.২৪৪, ৭৭.১৬৮ এবং ১.৮৭ ও বঙ্গোপসাগরের নমুনাসমূহের জন্য ৩৮.০৯১, ৬২.০২৩ এবং ২.০৬ পাওয়া গিয়েছিল। পর্যেষণা এলাকা সমূহের নমুনাগুলোতে কোন কৃত্রিম তেজস্ক্রিয় নিউক্লিয়াসের অস্তিত্ব পাওয়া যায়নি। ফুকুশিমায় পারমাণবিক বিস্ফোরণের জন্য পর্যেষণা এলাকা সমূহে কোন বিকিরণ ঝুঁকি পাওয়া যায়নি।

1. Introduction

Naturally occurring environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in the soils of each region in the world [1]. All radionuclides release ionizing radiation that may cause cancer.

Any amount of radiation dose may cause stochastic effect (e.g. cancer etc.). Uncontrolled radiation from any source is harmful to the occupational workers, public and environment. Since these radionuclides are not uniformly distributed, the knowledge of their distribution in soils plays an important role in radiation protection and measurement [2]. Also, the radioactivity of soils is essential for understanding changes in the natural background [3, 4]. For Bangladesh, tourism is an important economic activity. Important tourists' destinations and holiday resorts include beaches, river sides, parks and other historic places of interests. The Bay of Bengal (Patenga Sea Beach) and Karnaphuli river bank (Shah Amanat International Airport) are two important places for the people of the Chittagong City. The environmental quality of these places is an important attraction to large number of tourists and other holiday makers. But these two coastal places are linked to the Pacific Ocean through the Bay of Bengal. However, the wastes of the Fukushima nuclear accident were dumped naturally into the Pacific Ocean due to the effect of Tsunami. As a result, there could have some probabilities of increasing background radiation level of the natural and anthropogenic radionuclides present in the coastal belts of the present study areas. Among the environmental quality parameters, radiological hazard play a significant role in assessing the exposure of the public to natural radioactivity due to the presence of the uranium, thorium series and potassium-40. Sediment is mineral deposits formed through the weathering and erosion of rocks. These deposits found at different levels within the sand contain natural radionuclides that contribute to ionizing radiation exposure on earth [5]. The aim of the present study was categorized (1) to determine the specific activity of naturally occurring radionuclides ^{226}Ra, ^{232}Th, and ^{40}K and anthropogenic radionuclide ^{137}Cs and their corresponding radiological parameters in the sediment samples of the Karnaphuli River and the Bay of Bengal (Patenga sea beach) by using HPGe gamma ray spectrometry system, and (2) to obtain the correlation between Radium equivalent activity and the activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and the Chi-square (χ_R^2) values [6] of the activity of ^{226}Ra, ^{232}Th, ^{40}K.

2. Materials and Methods

2.1 Study Area

Bay of Bengal (Patenga Sea beach) and the Karnaphuli River (in front of Shah Amanat International Airport) were the area of interest of the present study which are located at the metropolitan area of Chittagong city in Bangladesh. Patenga sea beach is situated about 22 kilometers away and to the west of Chittagong city. On the way to the beach, one passes the Shah Amanat International Airport.

2.2 Sampling and Preparation

A total of 20 sediment samples were collected from the study area in which 10 from Karnaphuli River bank (Shah Amanat International Airport) and 10 from the Bay of Bengal (Patenga sea beach). All the samples were collected using sampling grid system maintaining a distance of about 50 m from each other. About 1 kg of sample was collected from each location and each of the samples was preserved in sequentially numbered plastic packet. All the samples were transferred to the laboratory then air-dried initially. All the samples were crushed to fine powder using mortar and pastel after removing the bulk materials and then oven dried at

105 °C and then homogenized by passing through a 1 mm mesh sieve. The homogenized samples were preserved into the cylindrical containers (7.5 cm diameter and 3 cm height) and marked individually with identification parameters and then weighed. All the sample containers were sealed tightly with cap and wrapped with Teflon and thick vinyl tapes around their screw necks and finally air tightened with polythene pack and stored for minimum four weeks prior to counting for allowing the establishment of secular equilibrium between the long lived ^{226}Ra, ^{232}Th and their decay products [7].

2.3 Gamma Spectrometry

2.3.1 Detector Specification

Gamma ray acquisitions of all the samples were done using a high-resolution p-type intrinsic High Purity Germanium (HPGe) coaxial detector mounted vertically and coupled to 16 K multichannel analyzer (Canberra). The detector was housed inside a lead shield to reduce the background radiation of the system. The experimental HPGe detector had a relative efficiency of 30% and a resolution of 1.78 keV for the gamma emission of 1333 keV of ^{60}Co. The spectrums of the gamma-rays were analyzed using the Genie 2000 software associated with the detector.

2.3.2 Efficiency and Specific Activity Measurement

Prior to the analysis, energy and efficiency calibrations were performed in the energy range up to 2700 keV to identify and quantify the radionuclides in the samples. The full-energy peak efficiency curve was plotted by measuring the reference samples IAEA/RGU-1 (U ore), IAEA/RGTh-1 (Th ore) and IAEA/RGK-

1 (K sulphate) from which the counting efficiencies of the γ-ray peaks were measured [8]. The geometry of the counting samples was the same as that of the standard samples and the counting time for all the samples was 10,000 sec. The background count due to naturally occurring radionuclides in the environment around the detector was subtracted from each sample count. Background count was taken by a blank plastic container of the same geometry of the detector. The background spectra at least should be taken for 20,000 sec [9]**.** In the present study, the background spectra were taken for 20000 sec. The counting efficiency of the detector was calculated by using the following formula [10]:

$$\% \text{ Efficiency} = \frac{CPS \times 100}{Activity \times Intensity} \quad \text{or,} \quad \varepsilon_f(\%) = \frac{CPS \times 100}{A_C \times I_\gamma}$$

For determining the activity concentration of ^{232}Th the most gamma yielding energies of ^{212}Pb (238.63 keV), ^{212}Bi (727.17 keV), ^{208}Tl (510.57 keV, 583.19 keV and 2614.53 keV) and ^{228}Ac (338.40 keV, 911.07 and 969.11 keV) were used. In case of the secular equilibrium, the gamma ray energies of ^{214}Pb (295.21 keV) and ^{214}Bi (1764.49 keV) and ^{214}Pb (351.92 keV) and ^{214}Bi (609.31 keV) were used to calculate the specific activity of ^{226}Ra. The ^{40}K and ^{137}Cs radionuclides were measured from their respective γ-ray energies 1460.75 keV and 661.66 keV respectively [11]. The activities of the natural radionuclide presented in the sediment samples were calculated by using the following formula [12, 13]:

$$\text{Activity} = \frac{CPS \times 100 \times 1000}{\varepsilon_f(\%) . \times I_\gamma \times w_s(gm)}$$

Where, CPS = Net counts per second (i.e., CPS for sample – CPS for background)

ε_f = Counting gamma energy efficiency of the detector in percentage.

I_γ = Intensity of the gamma ray or gamma yielding.

The results are expressed with the confidence limit of $\pm1\sigma$.

2.3.3 Calculation of Radiological Parameters

(**a**) The formula for calculating the outdoor absorbed dose rate in air at 1 m above the ground surface (in $nGy.h^{-1}$) using the conversion factors given in the UNSCEAR 1988 [14] report is

$$D_{outdoor} = (0.427\ C_{Ra} + 0.66\ C_{Th} + 0.0432\ C_K) \text{ ---------------------------------(1)}$$

Where C_{Ra}, C_{Th} and C_K are average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K respectively in the sediment samples.

(**b**) The indoor contribution is assumed to be 1.2 times higher than the outdoor dose [14]

$$D_{indoor} = D_{outdoor} \times 1.2\ (nGy.h^{-1}) \text{---(2)}$$

(**c**) The annual effective dose equivalent D_{eff} from outdoor terrestrial gamma radiation is [15]

$$D_{eff} = \text{Outdoor dose } (nGy.h^{-1}) \times 0.7\ (Sv.Gy^{-1}) \times 8{,}760\ (h.y^{-1}) \times 0.2 \text{ --------(3)}$$

Where 0.2 is the outdoor occupancy factor and 0.7 $Sv.Gy^{-1}$ is the quotient of effective dose equivalent rate to absorbed dose rate in air. For indoor exposure, using an occupancy factor of 0.8, the annual effective dose equivalent is

$$D_{eff} = \text{Indoor dose } (nGy.h^{-1}) \times 0.7\ (Sv.Gy^{-1}) \times 8{,}760\ (h.y^{-1}) \times 0.8 \text{ -------(4)}$$

(**d**) The total annual effective dose equivalent from terrestrial radiation is the sum of outdoor and indoor annual effective dose equivalent.

(**e**) The sediment is used for different purposes so the formula for calculating the external radiation hazard, H_{ext} and internal radiation hazard, H_{int} are as follows [16].

$$H_{ext} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \text{ --(5)}$$

$$H_{int} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \text{ --(6)}$$

The numerical quantities of equations (5) and (6) are in units of $Bq.kg^{-1}$ and A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K respectively.

(**f**) The formula for calculating the radium equivalent activities, Ra_{eq} and the representative level index values, I_γ are as follows [16]

$$Ra_{eq} = A_{Ra} + 1.43\ A_{Th} + 0.077\ A_K \text{ --(7)}$$

$$I_\gamma = (C_{Ra}/150 + C_{Th}/100 + C_K/1500) \text{ --(8)}$$

Where A_{Ra}, A_{Th} and A_K in equation (7) and C_{Ra}, C_{Th} and $C_K$in equation (8) are activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K respectively in the sediment samples respectively.

3. Results and Discussion

3.1 Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K

The mean activity concentrations of ^{226}Ra was found to be 38.33 ± 0.64& 48.89 ± 0.77 $Bq.kg^{-1}$ and ranged from 18.68 ± 2.22 to 66.94 ± 1.86 and 28.56 ± 2.27 to 73.61 ± 2.30 $Bq.kg^{-1}$for the Karnaphuli River and the Bay of Bengal respectively. The mean values of specific activities of these radionuclides for both the study areas were higher than those of the world average [1].

The activity concentrations of ^{223}Th had been found to be ranged from 19.36 ± 1.35 to 61.56 ± 1.69 and 29.17 ± 1.78 to 69.84 ± 1.94 $Bq.kg^{-1}$ with a mean value of

35.18 ± 0.49& 50.12 ± 0.61 Bq.kg^{-1} for the Karnaphuli River and the Bay of Bengal respectively. The mean activity concentration of ^{232}Th in the Karnaphuli River samples was lower than that of the world average [1]. However, the mean value of concentration for Bay of Bengal was higher than that of the world average value.

The activity concentrations of ^{40}K was found to be ranged from 290.01 ± 27.23 to 521.97 ± 58.08 and 314.61 ± 93.77 to 677.42 ± 105.86 Bq.kg^{-1} with the mean value of 355.31 ± 19.97 and 478.64 ± 31.35 Bq.kg^{-1} for the Karnaphuli River and the Bay of Bengal respectively. The mean concentration of ^{40}K in the Karnaphuli River samples was lower whereas for the Bay of Bengal which was higher than that of the world average. The comparison of the mean specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for both the study areas are given in Table 1 and represented in Figure 1. However, no artificial radionuclide like ^{137}Cs had been detected in the samples of present study area. The comparisons of these radionuclides for the Karnaphuli River and the Bay of Bengal with some other studies of the world are given in Tables 2 and 3, respectively.

Table 1: Comparison of mean activity concentration (in $Bq.kg^{-1}$) of the Karnaphuli River, the Bay of Bengal and UNSCEAR 2000.

Reference	**^{226}Ra**	**^{232}Th**	**^{40}K**	**^{137}Cs**
Karnaphuli river	38.33 ± 0.64	35.18 ± 0.49	355.31 ± 19.97	ND
Bay of Bengal	48.89 ± 0.77	50.12 ± 0.06	478.64 ± 31.35	ND
1	33	45	420	-

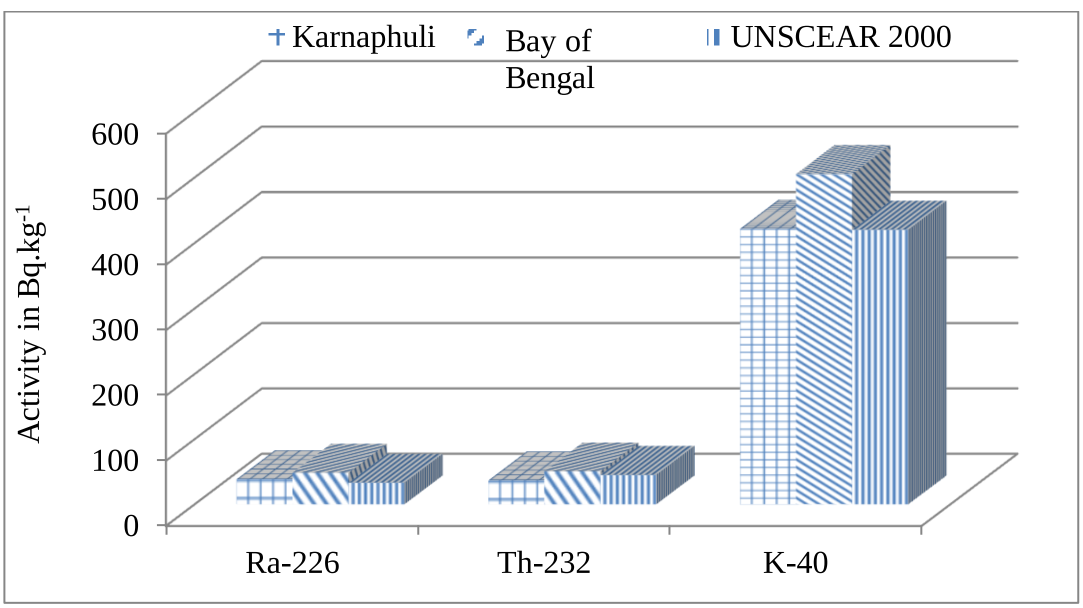

Figure 1: Comparison of average activities of the Karnaphuli River, the Bay of Bengal and UNSCEAR 2000.

Table 2: Comparison of the mean activity concentration (in Bq.kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K of the Karnaphuli River with some other rivers of the world and worldwide values.

Place	^{226}Ra	^{232}Th	^{40}K	Reference
Safaga, Egypt	25.3	21.4	618	17
Xianyang, China	31.1	44.9	776	17
Baoji, China	22.1	39	859	17
Brazil	7810	17770	2660	17
SaudiArabia	4.35 ± 0.028	3.3 ± 0.033	71.74 ± 7.21	18
Gediz, Turky	35.61-62.64	7.40-38.53	240.40-403.09	19
River Agbo, Nigeriain	9.40 ± 0.41	-	383.28 ± 9.24	20
River Afelumo, Nigeria	52.71 ± 0.97	-	495.12 ± 10.50	20
River Oyinmo, Nigeria	16.56 ± 0.05	-	514.85 ± 14.27	20
Wei River	10.4 - 39.9	15.3 - 54.8	514.8 - 1175.5	21
Cauvery River, Tamilnadu, India	5.31 ± 0.4	34.04 ± 1.4	401.11 ± 24.3	22
Nile River, Egypt	52 ± 7.3	76.2 ± 6.2	351.9 ± 17.6	23
Karnaphuli River	38.33±0.64	35.18±0.49	355.31±19.97	**(Present Study)**
World average	33	45	420	1

Table 3: Comparison of the mean activity concentration (in $Bq.kg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}K of the Bay of Bengal with some other Beaches of the world and worldwide values.

Place	^{226}Ra	^{232}Th	^{40}K	Reference
Persian Gulf, Iran	35	26	395	17
Coast of Greater Accra	22.04	108.60	29.78	17
Northwest Libya	7.5 (4 - 13.5)	4.2 (2.8 - 6.7)	27.5 (19 - 39.6)	24
Safaga, Red Sea; Egypt	28.82	14.03	558.39	22
Idku coast, Behara; Egypt	13.08	13.97	345.97	25
Chalatat and the Samila beaches, Thailand	41 ± 5	64 ± 7	248 ± 44	26
Kuakata, Bangladesh	29.48 ± 3.85	93.72 ± 15.62	551.24 ± 109.95	27
Beaches of Ghana	31.4	42.6	109.5	28
Japan	33	28	310	1
USA	40	35	370	1
Poland	26	21	410	1
Greece	25	21	360	1
Spain	32	33	470	1
Hong Kong SAR	59	95	530	1
Denmark	17	19	460	1
Bay of Bengal	48.89 ± 0.77	50.12 ± 0.61	478.64 ± 31.35	(**Present Study**)
World Average	33	45	420	1

3.2 Radium Equivalent Activity Ra_{eq}

The mean value of the Radium equivalent activity had been found to be 107.23 ± 6.89 and 150.47 ± 10.42 $Bq.kg^{-1}$ with a range of 85.26 ± 21.55 to 174.51 ± 20.51 and 109.74 ± 23.34 to 215.41 ± 23.73 $Bq.kg^{-1}$ for the Karnaphuli River and the Bay of Bengal respectively. The obtained mean value is lower for the Karnaphuli River but higher for the Bay of Bengal than that of the world average. The comparison of Ra_{eq} for both the study areas with the world average is shown Figure 2.

3.3 Gamma Dose Rates

The calculated values of indoor gamma dose rates were ranged from 43.68 ± 11.33 to 98.49 ± 20.63 and 68.69 ± 13.38 to 119.62 ± 19.78 $nGy.h^{-1}$ with an average of 61.93 ± 3.97 and 86.83 ± 6.00 $nGy.h^{-1}$ for the Karnaphuli River and the Bay of Bengal respectively. Whereas, the calculated mean value of outdoor gamma dose rate was found to be 51.61 ± 3.31 and 72.36 ± 5.00 $nGy.h^{-1}$ with a range from 36.39 ± 9.44 to 82.08 ± 20.63 and 57.25 ± 11.15 to 99.68 ± 16.48 $nGy.h^{-1}$ respectively, for the Karnaphuli River and the Bay of Bengal.

The external outdoor gamma dose rates were also measured by using β-γ survey meter of model LUDLUM 44-9. The measured outdoor dose rate for both the study areas was higher than that of the calculated value. The comparative data of the measured outdoor dose rate, calculated outdoor dose rate and world average is illustrated in Figure 3.

3.4 Representative Level Index

The value of representative level index found to be ranged from 0.55 ± 0.15 to 1.26 ± 0.26 and 0.88 ± 0.17 to 1.53 ± 0.25 $Bq.kg^{-1}$ with a mean value of 0.79 ± 0.05 and 1.11 ± 0.08 $Bq.kg^{-1}$ for the Karnaphuli River and the Bay of Bengal respectively. The obtained mean value is lower for the Karnaphuli River than that of the world average value whereas this value is higher for the Bay of Bengal.

3.5 Radiation Hazard Indices

The external hazard index were ranged from 0.20 ± 0.05 to 0.47 ± 0.11 and 0.31 ± 0.06 to 0.56 ± 0.09 with an average of 0.28 ± 0.02 and 0.41 ± 0.03 for the Karnaphuli river and the Bay of Bengal respectively. However, the mean value of internal hazard index had been found to be 0.37 ± 0.03 and 0.52 ± 0.04with a range of 0.25 ± 0.07 to 0.64 ± 0.15 and 0.39 ± 0.08 to 0.73 ± 0.15 for the Karnaphuli River and the Bay of Bengal respectively. The radiation hazard index for both the study areas have been found to be lower than that of the safety limit suggested by UNSCEAR 2000 [1]. So, the tourists and people of all occupation working there is free from the exposure of radiation danger for both the study areas.

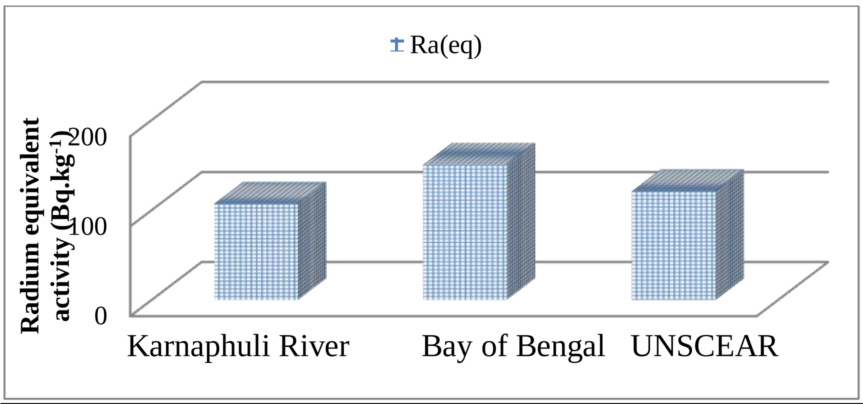

Figure 2: Comparison of Radium Equivalent Activities.

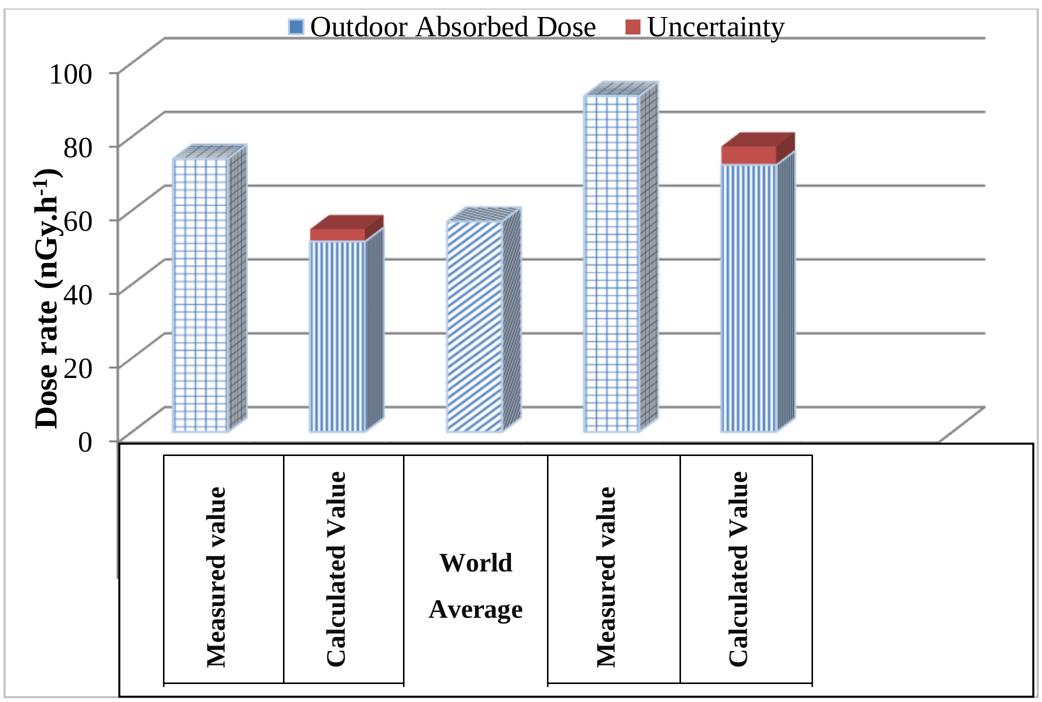

Figure 3: Comparison of Outdoor absorbed gamma dose rate of both study areas and the world average.

3.7 Annual and Total Annual Effective Dose Equivalents:

The mean value of outdoor annual effective dose equivalent had been found to be 0.06 ± 0.004 and 0.09 ± 0.006 $mSv.y^{-1}$ with the range of 0.04 ± 0.01 to 0.10 ± 0.021 and 0.07± 0.01 to 0.12 ± 0.02 $mSv.y^{-1}$ for the Karnaphuli River and the Bay of Bengal respectively. However, the indoor annual effective dose equivalent found to be ranged from 0.21 ± 0.06 to 0.48 ± 0.10 and 0.34 ± 0.07 to 0.59 ± 0.09 $mSv.y^{-1}$ with an average of 0.30 ± 0.02 and 0.43 ± 0.03 $mSv.y^{-1}$ for the Karnaphuli River and the Bay of Bengal respectively.

The total annual effective dose equivalent was found to be ranged from 0.04 ± 0.01 to 0.10 ± 0.02 and 0.07 ± 0.01 to 0.12 ± 0.02 $mSv.y^{-1}$ with an average of 0.37 ± 0.03 and 0.52 ± 0.05 $mSv.y^{-1}$ for the Karnaphuli River and the Bay of Bengal respectively. The comparisons of the radiological parameters of the present research work with some other countries of the world are given in Table 4 and 5.

Table 4: Comparison of radiological parameters with some other river sediments of the world.

Place	Radium Equivalent activity, Ra_{eq} ($Bq.kg^{-1}$)	Representative Gamma Index, Iγ ($Bq.kg^{-1}$)	External Radiation Hazard Index, H_{ext}	Total absorbed dose rate, D ($nGy.h^{-1}$)	Annual effective dose, H ($mSv.y^{-1}$)	Reference
Safaga, Egypt	<370	1.3	-	50.9	-	17
China	155	1.17	0.42	73.9	0.091	17
Baoji, China	144	-	039	69.6	0.085	17
Brazil	25800	230	70	14450	17.70	17
Saudi Arabia	20.16	0.149		9.54	0.0115	18
River Agbo	84.64	-	-	41.74	-	20
River Afelumo	512.46	-	-	243.25	-	20
River Oyinmo	113.42	-	-	55.79	-	20
China	<370	≈1	<1	68.8	0.079	23
Cauvery River, TN, India	-	-	-	40.73±1.8	0.25	22
USA	119	-	-	56	-	1
Karnaphuli River	**107.23 ± 6.89**	**0.79 ± 0.05**	**0.29±0.02**	**51.61 ± 3.31**	**0.06±0.00**	**(Present Study)**

Table 5: Comparison of radiological parameters with some other beaches of the world.

Place	Radium Equivalent activity, Ra_{eq} (Bq.kg^{-1})	Representative Gamma Index, Iγ (Bq.kg^{-1})	External Radiation Hazard Index, H_{ext}	Total absorbed dose rate, D (nGy.h^{-1})	Annual effective dose, H (mSv.y^{-1})	Reference
Persian Gulf, Iran	<370	-	<1	37	-	17
Coast of Greater Accra	9	0.48	-	77.02	0.09	17
Northwest Libya	-	-	-	4.4 ±1.3	0.0054±0.0016	24
Safaga, Red Sea; Egypt	370	1	≤1	59	-	22
Idku coast, Behara; Egypt	57.67	0.4575	0.16122	29.71	0.03645	25
Chalatat and the Samila beaches, Thailand	152±18	-	-	69±8	-	26
Ghana	101.0	0.71		54.08	0.066	28
Kuakata, Bangladesh	98.81 To 271.17	0.8 to 3.75	-	98.33	-	27
USA	119	-	-	56	-	1
China	125	-	-	59	-	1
Hong Kong SAR	236	-	-	108	-	1
Japan	97	-	-	45	-	1
Denmark	80	-	-	39	-	1
Switzerland	104	-	-	49	-	1
Poland	88	-	-	42	-	1
Greece	83	-	-	40	-	1
Spain	115	-	-	55	-	1
Bay of Bengal	**150.47 ± 10.42**	**1.11 ± 0.08**	**0.41 ± 0.03**	**72.36 ± 5.00**	**0.52 ± 0.05**	**(Present Study)**

3.8 Correlation

In the present study, a high degree of correlation between radium equivalent activities and ^{226}Ra activities was obtained for both the study areas which are represented in Figure 4. The dependence is higher for the Bay of Bengal samples than that of Karnaphuli River samples. A very high degree of correlation ($r = 0.9551$) had been found to exist between the radium equivalent activities and ^{232}Th activities for the Bay of Bengal but a high degree of correlation ($r = 0.8361$) was found for the Karnaphuli River samples which is shown in Figure 5. This indicates a strong dependence of Ra_{eq} on ^{232}Th concentration for both the study areas. However, the correlation between Ra_{eq} and ^{40}K for both the study areas had been found to be very poor ($r = 0.0011$ and 0.0332 for the Bay of Bengal and the Karnaphuli river respectively). The poor correlation between radium equivalent activities and ^{40}K in both the study areas indicates that Ra_{eq} varied slightly on the presence of ^{40}K which is given in Figure 6. It is obvious that all these correlations were positive as evident from the formula of radium equivalent activity.

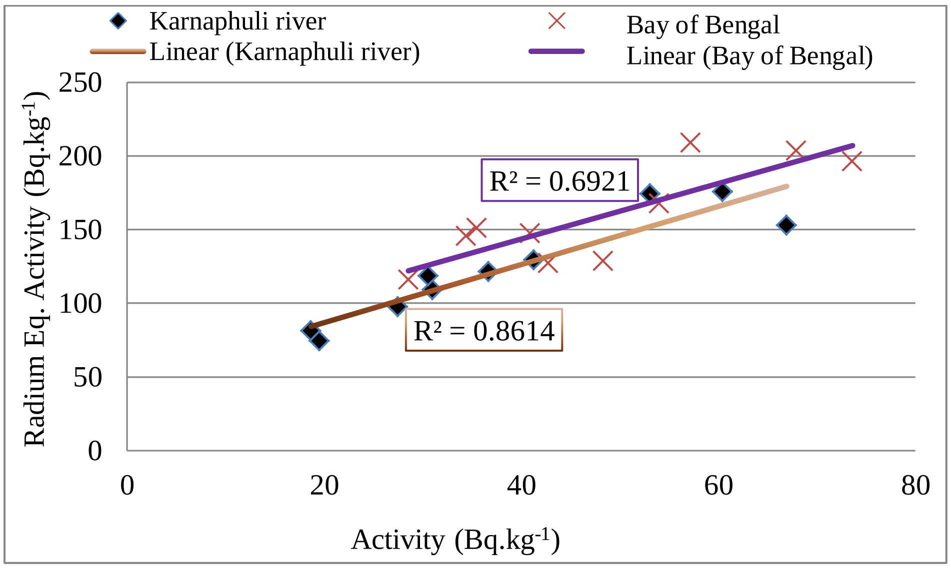

Figure 4: Correlation between Ra_{eq} and ^{226}Ra for river and sea samples.

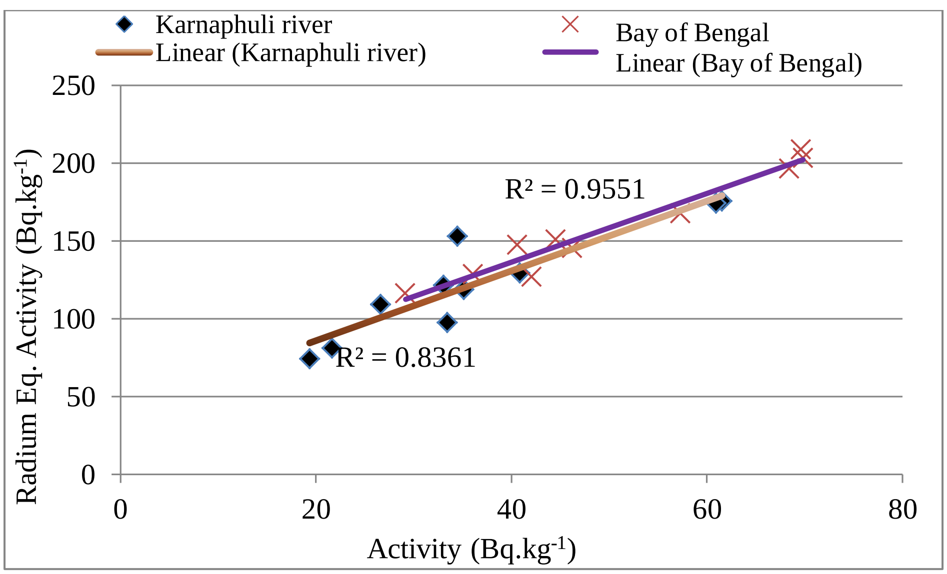

Figure 5: Correlation between Ra_{eq} and ^{232}Th in river and sea samples.

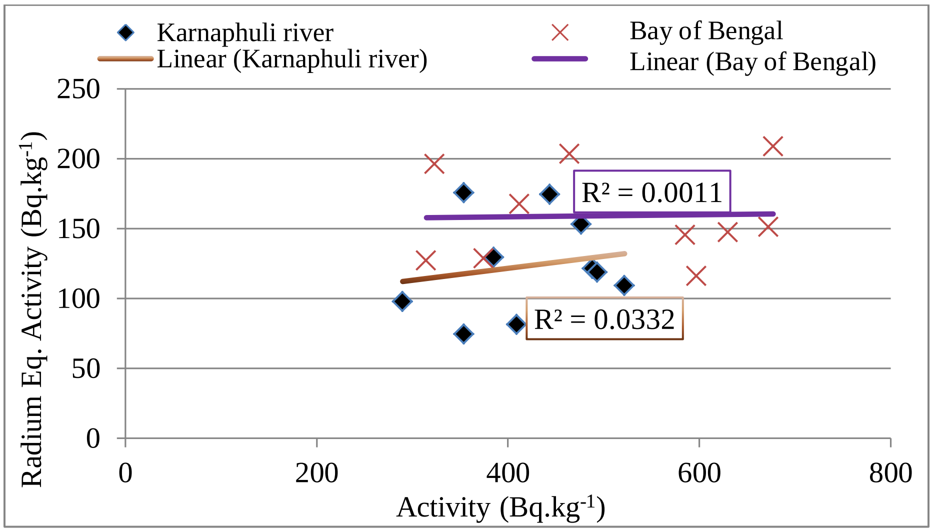

Figure 6: Correlation between Ra_{eq} and ^{40}K for river and sea samples.

3.9 Chi-Square per Degree of Freedom (χ_R^2)

The values of Chi-square per degree of freedom (χ_R^2) for ^{226}Ra, ^{232}Th and ^{40}K were 70.24, 77.17 and 1.87 respectively for the Karnaphuli River samples and 38.09, 62.02 and 2.06 respectively for the Bay of Bengal samples. The low χ_R^2 values for ^{40}K in both the study areas indicate the distributions of ^{40}K concentration were nearly uniform. The higher χ_R^2 values for ^{232}Th indicate a wide distribution of ^{232}Th activity concentrations. However, the ^{226}Ra activity was more widely distributed in the Karnaphuli River than that of the Bay of Bengal.

4. Conclusions

In the present work, the following key points are drawn: (1) The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in sediment of the Karnaphuli River are lower than that of the Bay of Bengal, (2) the mean activity concentration of ^{232}Th and ^{40}K are lower but ^{226}Ra is higher than that of the world average in sediment of the Karnaphuli River, (3) the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the Bay of Bengal are higher than the world average value, (4) the obtained correlations are positive and the χ_R^2 values indicate that the distribution is within the safety limit and (5) the obtained values of external and internal radiation hazard indices are less than that of the permissible value 1 [14]. So, on the basis of values obtained, it is concluded that no harmful radiation effects are exposed to the public going to the beaches and river sides for recreation or to the sailors and fishermen involved in their activities in the area as a result of the activity of coastal sediments. Hence, no radioactive threat is obtained in the costal belts linked into the Pacific Ocean through the Bay of Bengal of Chittagong city, Bangladesh due to the nuclear reactor accident at Fukushima, Japan.

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