Scientific Research Publishing

Journal of Environmental Protection, 2020, 11, 767-778
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

The Activity Concentrations, Radiation Contamination, and Hazards from Wastes and Soil Samples in Nasirabad Industrial Area, Chattogram, Bangladesh

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How to cite this paper: Mojumder, M.D.A., Ahmed, M., Kamal, M., Hossen, M.B. and Rashid, Md.A. (2020) The Activity Concentrations, Radiation Contamination, and Hazards from Wastes and Soil Samples in Nasirabad Industrial Area, Chattogram, Bangladesh. *Journal of Environmental Protection*, **11**, 767-778.
https://doi.org/10.4236/jep.2020.1110047

Received: August 13, 2020
Accepted: September 26, 2020
Published: September 29, 2020

Abstract

Soils and other solid wastes from industrial areas of Nasirabad, Chattogram are usually dumped or used for land development. Information about the radioactivity level presented on these soil and wastes enables one to assess any possible radiological hazard to humankind by the use of such materials. A total of 37 (31 soils and 6 solid waste) samples near from different types of industries along four kilometre range were collected. The presence and activity concentrations of naturally occurred radioactive materials (NORM) and anthropogenic radionuclides in the samples were estimated using HPGe detector of 40% relative efficiency. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were found to be ranging from 8 ± 2 to 131 ± 18.33 with an average of 21 Bq·kg^{-1}, 10 ± 2.69 to 133 ± 15.96 with an average of 40 Bq·kg^{-1} and 81 ± 22.68 to 930 ± 260.40 with an average of 449 Bq·kg^{-1} respectively. Besides this, some hazard indices like, the radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), and the activity concentration index (I_{γ}) were calculated to assess the radiation hazard in this region. The averages of calculated hazard indices were within the normal limits, except the activity concentration index, which shows elevated values. The outcomes of this study could serve as important baseline radiological data for future epidemiological studies and environmental monitoring initiatives in the study area.

Keywords

Industrial Contamination, Gamma Spectrometry, Activity Concentration, Hazard Index

1. Introduction

Human exposure to ionizing radiation is one of the scientific subjects that attract public attention over the time since the natural radioactivity from primordial origins is the vast majority to detect on the earth and is responsible for most of the total radiation exposure of the mankind (UNSCEAR, 2000). Among these ^{226}Ra is the most abounded progeny of ^{238}U (99%) that exists in the geo-surface media, generally in soil, in water and/or in the earth-born materials with appearing activity [1]. The radioactive substance of thorium occurs naturally in the earth's crust in combination with other minerals such as silica, and almost 99% of natural thorium exists in the form of ^{232}Th [2]. Underground mine rocks usually contain a more intense form of thorium. Wind, water action and other natural weathering break these rocks, and make the thorium and all other components of the rocks become a part of the soil [3]. Moreover, the soil containing a high amount of mud materials shows elevated contents of thorium [4]. ^{39}K (93.2581%) and ^{41}K (6.7302%), the two natural isotopes of potassium are compulsory for living species; however, various health hazards are cause of the strong gamma radiation (1460 keV) emitted from the primordial ^{40}K (0.0118%) [5] [6]. Different physicochemical forms of the aforementioned radionuclides trigger up their mobility and biological uptake. For instance, radium especially bonds to organic matter and has an affinity for hard tissue because of its chemical similarity to calcium [7]. While potassium and thorium favourably bond to clays, and hence these are more radioactive than the other sedimentary rocks. Thorium enters the body mainly through inhalation of contaminated dust and swallowed in water and/or with food. Most of its portion ejects out, if some portion remains it will be deposited to bones, where it may remain for many years. On the other hand, the potassium ingested through the food chain and finally deposited on muscular cells.

Chattogram, the commercial capital of Bangladesh is famous for its industrial affluence. Our study region, Nasirabad Industrial area has around 25 industries of a wide variety, like steel industries, metal & plastic processing industries, food processing industries, paint & chemical production factories, oil refining plants, silver recycling, woodcutting and textile mills [8]. These factories are illegitimately discharging a huge amount of pollutants to the ambient continuously.

Despite being the industrial area, around 100 thousand inhabitants live permanently in the span of 8 square kilometre of this study area [9]. Following the radiological health hazards particularly from the external exposure via gamma radiation, the concentrations of NORMs and contamination due to anthropogenic radionuclides in this area should be the subject of periodic monitoring. This study has been conducted to investigate the level of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) and artificial radionuclides (^{137}Cs) in the soils of Nasirabad Industrial area due to its importance in commerce and radiological assessment to the working and living population.

The results of this study are expected to contribute to the development of environmental regulatory frameworks, and raising public awareness about radiation health hazard.

2. Experimental Procedure

2.1. Sample Collection and Preparation

Nasirabad Industrial area is in the northern side of Chattogram City Corporation. The investigated samples of soil and solid wastes were collected from the area lies between the longitudes of 91˚48.534'E - 91˚49.249'E and the latitudes of 22˚22.465'N - 22˚23.660'N (Figure 1). All the samples were collected in the mid of winter so that it's expected to get the maximum contamination level, apart from washout of surface contaminant. All the labelled samples were brought to Atomic Energy Centre, Chattogram for ensuing preparation and investigation. To make moisture free for achieving proper matrix, each sample was oven-dried at about 105˚C until getting the constant weight following the removal of unwanted objects. Dried samples were blended by using a domestic blender and a porcelain mortar pestle and then sieved with 500 μm pore size to make homogenized. Later, around 200 g of each sample was kept in a zip lock bag and stored in desiccators for further removal of moisture before taken into individual mini-Marinelli (~250 ml) beakers. The container was simply shaken by hand to settle down the dry powder sample homogeneously. For allowing the secular equilibrium between ^{232}Th and ^{226}Ra and their progenies, the prepared samples

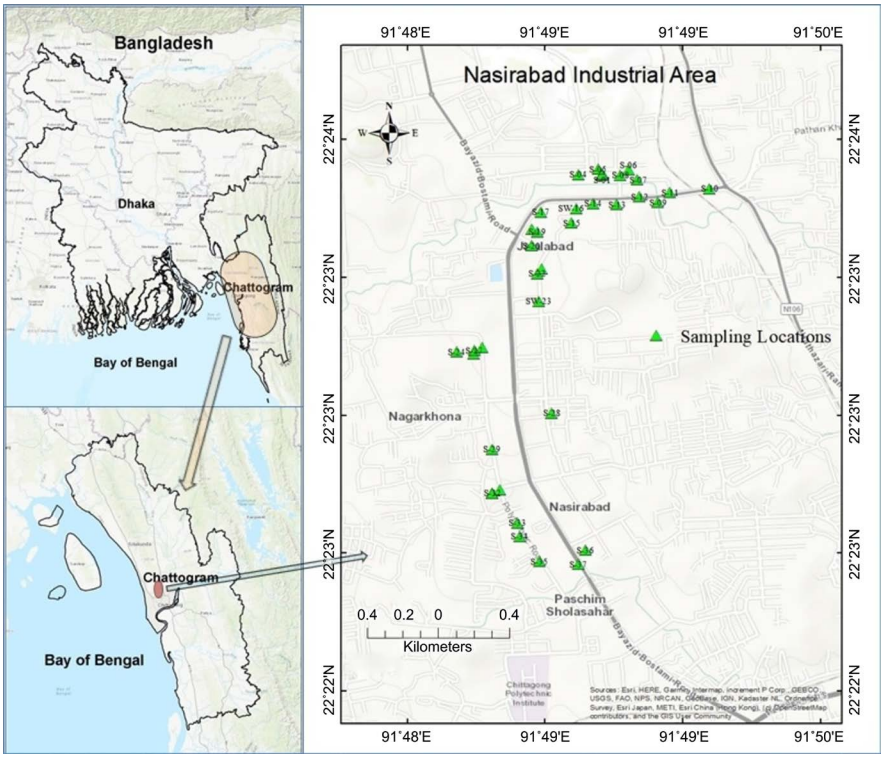

Figure 1. Sampling location.

containers were sealed tightly and wrapped with wide vinyl tapes around their screw necks to ensure airtight condition and were stored for four weeks before the measurement of radioactivity [10].

2.2. Measurement by Gamma-Ray Spectrometry

The activity concentrations of NORM's and TENORM's in the samples were detected using a liquid nitrogen-cooled coaxial p-type HPGe gamma ray detector (BSI, GCD 40190, S/N 2465-17) having a sensitive area of 63.3 mm diameter and 61.3 mm depth, operating on +2200 Volt bias voltage. The detector having relative efficiency for energy 1332 keV to NaI(Ti) is 43.1% with Peak to Compton ratio 71:1, an energy resolution of 1.74 keV FWHM at the 1332 keV peak of ^{60}Co, and capability to detect photon energy ranging from 40 keV to 10,000 keV was enclosed in a cylindrical lead (^{206}Pb) shield of 10 cm thick jacketed by a 5 mm steel outer housing with 1mm of tin to lower the background. This shielding arrangement is like a fixed bottom and removable cover type to place the sample on the top of the detector.

The counting system was connected to a 16 k (although for our study it was set to 8 k, as it's better efficient at 8 k with HPGe for full range gamma spectra analysis) digital multi-channel analyser (MCA 527, GBS Elektronik GmbH) with associated electronics for data acquisition of photo-peak areas. SpectraLineGP software was used to analyse the gamma rays emitted from the samples. Energy and efficiency calibration were performed using a standard (Code: 8501-EG-SVE, Eckert & Ziegler Analytics), certified multi-nuclide gamma ray source (^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y, ^{60}Co) having homogeneously distributed activity, maintaining the same geometry and density as the beakers containing the samples. In order to minimize the statistical counting error, the samples were counted for a period of 15,000 s. An empty container was counted under the same conditions to determine the background counts and was deducted from the counts of each sample to obtain the net counts as well as the specific activities.

For spectrum analyses, the single transition gamma ray line 1460.822 keV was used to determine the activity concentrations of ^{40}K. The gamma ray photo-peaks of 295.221 keV and 351.922 keV from ^{214}Pb, and 609.32 keV, 1120.31 keV, and 1764.551 keV from ^{214}Bi were used to determine the activity concentrations of ^{226}Ra. The activity concentrations of ^{232}Th were determined using the net counts under the 238.63 keV and 300.087 keV photo-peaks from ^{212}Pb, 911.205 keV, and 968.97 keV photo peaks from ^{228}Ac, and 583.19 keV and 2614.533 keV from ^{208}Tl. For the evaluation of ^{226}Ra and ^{232}Th activity, a weighted mean approach [11] was applied using the aforementioned gamma lines.

The activity concentration of each radionuclide of interest in each sample was evaluated using the following equation [12]:

$$A = \frac{N \times 1000}{\varepsilon_\gamma \times I \times t_s \times w} \tag{1}$$

where "A" the activity concentration of the radionuclide in the sample, in Bq/kg, "N" the net counts under the corresponding photo-peak, "ε_γ" the detection efficiency corresponding to each specific gamma ray, "I" the intensity of the corresponding gamma ray energy, "t_s" the counting time in seconds and "w" the mass of the sample in gram.

The radioactivity of each sample is being reported with the counting error of one sigma. The analysis software Spectra Line GP calculates the standard deviation (SD) from the several values of uncertainty impute by the operator and their average for a radionuclide using Equation (2).

$$SD, \sigma = \left(\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \cdots + (x_n - \bar{x})^2}{n} \right)^{1/2} \quad (2)$$

where, "n" is the total number of samples, "$\bar{x}$" is the arithmetic average and "x_n" indicates individual samples value.

3. Results and Discussion

In this study, 37 samples of soils and industrial wastes were analysed to detect the level of radiation contamination and NORM's. Among them, six samples are throw-out solid (mud, slug, and rust) waste collected near the metal processing industries. Table 1 shows the distribution of detected radionuclides and their specific activity (in Bq·kg^{-1}) on dry-weight basis. Among them, 10 samples have the ^{226}Ra bellow the detection limit, whereas only in 4 samples ^{232}The was undetected and apart from this, ^{40}K was present as dominating amount over the other radionuclides in every sample.

Table 1. Activity concentration of detected radionuclides.

Samples category	Samples ID	Activity concentration (Bq·kg^{-1})		
		Th-232	**Ra-226**	**K-40**
Soil samples	S-01	52 ± 7.28	16 ± 3.36	530 ± 74.20
	S-02	34 ± 6.12	10 ± 2.91	520 ± 78.00
	S-04	29 ± 4.93	8 ± 2.49	81 ± 22.68
	S-05	133 ± 15.96	131 ± 18.33	388 ± 69.76
	S-06	-	-	126 ± 29.01
	S-07	40 ± 7.68	-	508 ± 96.54
	S-08	-	-	120 ± 34.85
	S-09	25 ± 7.37	15 ± 3.98	426 ± 80.95
	S-10	56 ± 7.85	15 ± 3.83	575 ± 86.22
	S-11	20 ± 3.87	8 ± 2.00	300 ± 47.95
	S-12	36 ± 6.82	23 ± 4.65	552 ± 82.78
	S-13	31 ± 4.67	16 ± 3.11	379 ± 56.84
	S-14	31 ± 5.66	16 ± 3.78	443 ± 70.93

Continued

	S-15	42 ± 6.27	17 ± 3.51	540 ± 81.06
	S-17	72 ± 10.76	32 ± 6.01	865 ± 129.72
	S-19	47 ± 7.02	17 ± 3.64	569 ± 91.00
	S-20	27 ± 8.10	-	450 ± 99.00
	S-22	-	-	120 ± 48.00
	S-24	66 ± 9.24	21 ± 4.58	739 ± 96.06
	S-25	47 ± 7.52	20 ± 4.40	610 ± 97.60
	S-27	52 ± 7.28	18 ± 3.60	610 ± 85.40
	S-28	10 ± 2.69	-	130 ± 36.32
	S-29	37 ± 5.92	16 ± 3.52	570 ± 85.50
	S-30	56 ± 7.84	26 ± 4.68	690 ± 96.60
	S-31	38 ± 6.08	16 ± 3.36	410 ± 61.50
	S-32	-	-	930 ± 260.40
	S-33	44 ± 6.60	15 ± 3.45	520 ± 83.20
	S-34	30 ± 5.10	14	450 ± 67.50
	S-35	38 ± 6.08	16	400 ± 64.00
	S-36	25 ± 6.25	-	400 ± 96.00
	S-37	37 ± 5.55	20	410 ± 65.60
Average		40 ± 6	19 ± 4	463 ± 80
Standard deviation		25	24	206
Solid waste samples	SW-03	21 ± 6.09	-	220 ± 88.00
	SW-16	26 ± 4.42	10 ± 2.77	440 ± 66.00
	SW-18	17 ± 8.50	-	370 ± 148.00
	SW-21	47 ± 7.99	20 ± 4.80	660 ± 112.20
	SW-23	29 ± 5.51	13 ± 3.51	230 ± 62.10
	SW-26	27 ± 4.86	9 ± 2.55	320 ± 51.20
Average		28 ± 6	10 ± 2	373 ± 88
Standard deviation		10	7	163
Total average		40.07 ± 6.78	20.59 ± 4.20	448.65 ± 81.15
Total standard deviation		21.68	22.70	200.51

-bellow detection limit.

In sampling site s-05, it shows that the activity of ^{226}Ra and ^{232}Th are 131 ± 18.33 and 133 ± 15.96 Bq·kg^{-1} respectively, which is quite elevated and almost four times higher than the world average [13], while the average activity of these two particular primordial radionuclides for all samples is still below with compared to the world average, according to UNSCEAR (2000) report [13]. The most reasonable cause for much raised up activity in the aforementioned site is unauthorized disposal of the iron ore residue from the nearest metal processing

factory. The distribution of ^{232}Th over all samples is quite precise, as it shows a low standard deviation and almost 78% values are in the first sigma variance. For ^{226}Ra the precision was also found in quit good, as almost 51% values are in first sigma, while 68% samples give the concentration of ^{40}K within standard deviation. No ^{137}Cs or other man-made isotopes have been detected in our studied sample, which indicates the sampling area is free from anthropogenic radionuclide contamination.

The biological effect of these ionizing radiation can be estimated by the means of absorbed dose. The measured activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are converted into doses rate (D, nGy·h^{-1}) presenting in **Table 1** is done by applying Equation (3), which has been extracted from UNSCEAR, 2000 report.

$$D = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (3)$$

were, C_{Ra}, C_{Th} and C_K are the activity concentration (Bq·kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K respectively.

Ten samples from all studied data show the higher value of dose rate compared to world average (57 nGy·h^{-1}) reported by UNSCEAR with the maximum value of 157 nGy·h^{-1} in sample s-05. This implies that the area of the collected sample will not be a good choice for living.

Annual effective dose equivalent (AEDE) received by an individual was also estimated from the dose rate. In this case, the quotient of effective dose rate to absorbed dose rate in air is taken as 0.7 Sv·Gy^{-1} and 20% occupancy for outdoor while 80% for indoor as per suggestion of UNSCEAR report for environmental exposure to gamma rays of moderate energy [13].

$$\mathrm{AEDE(outdoor)},\ \mathrm{mSv\cdot y^{-1}} = D\left(\mathrm{nGy\cdot h^{-1}}\right)\times 8760\ \mathrm{h}\times 0.7\ \mathrm{Sv\cdot Gy^{-1}}\times 0.2\times 10^{-6} \quad (4a)$$

$$\mathrm{AEDE(indoor)},\ \mathrm{mSv\cdot y^{-1}} = D\left(\mathrm{nGy\cdot h^{-1}}\right)\times 8760\ \mathrm{h}\times 0.7\ \mathrm{Sv\cdot Gy^{-1}}\times 0.8\times 10^{-6} \quad (4b)$$

Most of the samples have AEDE (outdoor) bellow the world average (0.07 mSv·y^{-1}), except ten samples having the higher. On the other hand, only the sample S-05 and S-17 exhibits the AEDE (indoor) higher than world average (0.41 mSv·y^{-1}) mentioned in UNSCEAR 2000. But in combined annual effective dose (indoor + outdoor), sample S-05 (0.963 ± 0.129 mSv·y^{-1}), S-17 (0.576 ± 0.090 mSv·y^{-1}) and S-24 (0.492 ± 0.072 mSv·y^{-1}) show the value higher than the world average (0.48 mSv·y^{-1}), whereas the average annual dose (0.29 ± 0.05 mSv·y^{-1}) for all samples is still below the world average. **Table 2** listed the examined value of absorbed dose rate, annual effective dose equivalent for indoor and outdoor.

Radium equivalent activity (Ra_{eq}) concentration in Bq·kg^{-1}, is the widely used hazard index which implies the comparison of activity concentration of radium, thorium and potassium presented in the samples. It is assumed that 370 Bq·kg^{-1} of ^{226}Ra, 259 Bq·kg^{-1} of ^{232}Th and 4810 Bq·kg^{-1} of ^{40}K produced the same gamma-ray dose. Based on this, Ra_{eq} was calculated by using Equation (5) for this study [14].

$$Ra_{eq}\left(\mathrm{Bq\cdot kg^{-1}}\right) = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (5)$$

Table 2. Dose rate (D), annual effective dose equivalent, radium equivalent activity (Ra_{eq}) and activity concentration index (I_{γ}) distribution among the studied samples.

Samples category	Samples ID	Dose rate (D) in nGy·h^{-1}	AEDE in mSv·y^{-1}		Ra_{eq} in Bq·Kg^{-1}	I_{γ}
			outdoor	Indoor		
Soil samples	S-01	60.90 ± 9.04	0.075 ± 0.011	0.299 ± 0.044	131.17 ± 19.48	0.49 ± 0.07
	S-02	46.70 ± 8.29	0.057 ± 0.010	0.229 ± 0.041	98.36 ± 17.67	0.38 ± 0.07
	S-04	24.73 ± 5.07	0.030 ± 0.006	0.121 ± 0.025	56.01 ± 11.29	0.20 ± 0.04
	S-05	157.00 ± 21.02	0.193 ± 0.026	0.770 ± 0.103	351.00 ± 46.53	1.23 ± 0.16
	S-06	5.26 ± 1.21	0.006 ± 0.001	0.026 ± 0.006	9.71 ± 2.23	0.04 ± 0.01
	S-07	45.60 ± 8.66	0.056 ± 0.011	0.224 ± 0.043	96.92 ± 18.41	0.37 ± 0.07
	S-08	5.01 ± 1.45	0.006 ± 0.002	0.025 ± 0.007	9.25 ± 2.68	0.04 ± 0.01
	S-09	39.43 ± 9.67	0.048 ± 0.012	0.193 ± 0.047	82.70 ± 20.76	0.31 ± 0.08
	S-10	64.64 ± 10.11	0.079 ± 0.012	0.317 ± 0.050	139.17 ± 21.69	0.52 ± 0.08
	S-11	28.50 ± 5.26	0.035 ± 0.006	0.140 ± 0.026	60.21 ± 11.23	0.23 ± 0.04
	S-12	55.45 ± 9.72	0.068 ± 0.012	0.272 ± 0.048	117.12 ± 20.78	0.44 ± 0.08
	S-13	41.80 ± 6.63	0.051 ± 0.008	0.205 ± 0.033	89.28 ± 14.17	0.33 ± 0.05
	S-14	45.09 ± 8.13	0.055 ± 0.010	0.221 ± 0.040	95.57 ± 17.34	0.36 ± 0.06
	S-15	55.52 ± 8.79	0.068 ± 0.011	0.272 ± 0.043	118.14 ± 18.72	0.44 ± 0.07
	S-17	93.99 ± 14.68	0.115 ± 0.018	0.461 ± 0.072	200.78 ± 31.38	0.75 ± 0.12
	S-19	59.63 ± 9.72	0.073 ± 0.012	0.293 ± 0.048	127.27 ± 20.69	0.48 ± 0.08
	S-20	35.07 ± 9.02	0.043 ± 0.011	0.172 ± 0.044	73.26 ± 19.21	0.29 ± 0.07
	S-22	5.00 ± 2.00	0.006 ± 0.002	0.025 ± 0.010	9.24 ± 3.70	0.04 ± 0.02
	S-24	80.29 ± 11.70	0.098 ± 0.014	0.394 ± 0.057	172.09 ± 25.19	0.65 ± 0.09
	S-25	63.07 ± 10.64	0.077 ± 0.013	0.309 ± 0.052	134.18 ± 22.67	0.51 ± 0.08
	S-27	65.16 ± 9.62	0.080 ± 0.012	0.320 ± 0.047	139.33 ± 20.59	0.52 ± 0.08
	S-28	11.43 ± 3.14	0.014 ± 0.004	0.056 ± 0.015	24.25 ± 6.65	0.09 ± 0.03
	S-29	53.51 ± 8.77	0.066 ± 0.011	0.262 ± 0.043	112.80 ± 18.57	0.43 ± 0.07
	S-30	74.61 ± 10.93	0.092 ± 0.013	0.366 ± 0.054	159.21 ± 23.33	0.60 ± 0.09
	S-31	47.44 ± 7.79	0.058 ± 0.010	0.233 ± 0.038	101.91 ± 16.79	0.38 ± 0.06
	S-32	38.78 ± 10.86	0.048 ± 0.013	0.190 ± 0.053	71.61 ± 20.05	0.31 ± 0.09
	S-33	55.19 ± 9.05	0.068 ± 0.011	0.271 ± 0.044	117.96 ± 19.29	0.44 ± 0.07
	S-34	43.35 ± 7.38	0.053 ± 0.009	0.213 ± 0.036	91.55 ± 15.71	0.35 ± 0.06
	S-35	47.02 ± 7.97	0.058 ± 0.010	0.231 ± 0.039	101.14 ± 17.14	0.38 ± 0.06
	S-36	31.78 ± 7.78	0.039 ± 0.010	0.156 ± 0.038	66.55 ± 16.33	0.26 ± 0.06
	S-37	48.69 ± 7.84	0.060 ± 0.010	0.239 ± 0.038	104.48 ± 16.79	0.39 ± 0.06
Average		49.34 ± 8.45	0.061 ± 0.010	0.242 ± 0.041	106.52 ± 18.02	0.40 ± 0.07
Standard deviation		29.12	0.04	0.14	65.28	0.23
Solid waste samples	SW-03	21.86 ± 7.35	0.027 ± 0.009	0.107 ± 0.036	46.97 ± 15.48	0.18 ± 0.06
	SW-16	38.63 ± 6.70	0.047 ± 0.008	0.189 ± 0.033	80.96 ± 14.17	0.31 ± 0.05
	SW-18	25.70 ± 11.31	0.032 ± 0.014	0.126 ± 0.055	52.80 ± 23.55	0.21 ± 0.09

Continued

SW-21	65.15 ± 11.72	0.080 ± 0.014	0.320 ± 0.058	138.03 ± 24.87	0.52 ± 0.09
SW-23	33.11 ± 7.54	0.041 ± 0.009	0.162 ± 0.037	72.18 ± 16.17	0.27 ± 0.06
SW-26	33.58 ± 6.25	0.041 ± 0.008	0.165 ± 0.031	71.75 ± 13.44	0.27 ± 0.05
Average	36.34 ± 8.48	0.045 ± 0.010	0.178 ± 0.042	77.12 ± 17.95	0.29 ± 0.07
Standard deviation	15.34 ±	0.02	0.08	32.49	0.12
Total average	47.23 ± 8.45	0.06 ± 0.01	0.23 ± 0.04	100.67 ± 17.97	0.38 ± 0.07
Total standard deviation	27.62	0.03	0.14	61.10	0.22

where, C_{Ra}, C_{Th} and C_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bq·kg^{-1} respectively. The Ra_{eq} results for the samples are found in the range of 9.24 ± 3.70 to 351 ± 46.53 Bq·kg^{-1} with an average of 100.67 ± 17.97 Bq·kg^{-1}, which is still below the world average 370 Bq·kg^{-1} if the materials are intended to use as building materials [13].

In order to assess the safety level of radiation, the European Commission proposed an index called gamma activity concentration index (I_γ). I_γ is calculated by using the following formula, Equation (6). [15]

$$I_\gamma = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \tag{6}$$

where, C_{Ra}, C_{Th} and C_K are the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in Bq·kg^{-1}. If the samples are used as building materials and/or land development, the activity concentration index shall not exceed the following values shows in **Table 3** depending on the dose limit criterion [15].

The distribution of the value of I_γ for the collected samples from Nasirabad industrial area, that are used for land development and house construction was studied and presented in **Table 2**. The average I_γ for soil samples is 0.40 ± 0.07 and for solid waste is 0.29 ± 0.07, and for all samples is 0.38 ± 0.07, which are <1. Nonetheless, the soil sample S-05 having the highest I_γ value, 1.23 ± 0.16. Therefore the annual effective dose delivered by the all other sample is smaller than the annual effective dose constraint of 1 mSv·y^{-1}. Hence, except sample S-05, all others can be allowed for land development and building materials for household construction.

External (H_{ex}) and internal (H_{in}) hazard index are another two dimensionless parameter to estimate the level of hazard due to radiological constituent. The prime objective of this H_{ex} and H_{in} is to estimate and take preventive measures for limiting the annual permissible dose for the public (1 mSv·y^{-1}) suggested by IAEA [16]. Equation no (7a) and (7b) were used to calculate the aforementioned indices and the deduced value is presented in **Figure 2**.

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{7a}$$

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{7b}$$

Table 3. Reference level of I_γ for different dose criterion.

Dose criterion	0.3 mSv·y^{-1}	1 mSv·y^{-1}
Materials used in bulk amount. e.g. land development, concrete, etc.	$I_\gamma \leq 0.5$	$I_\gamma \leq 1$
Superficial and other materials with restricted use. e.g. tiles, board, etc.	$I_\gamma \leq 2$	$I_\gamma \leq 6$

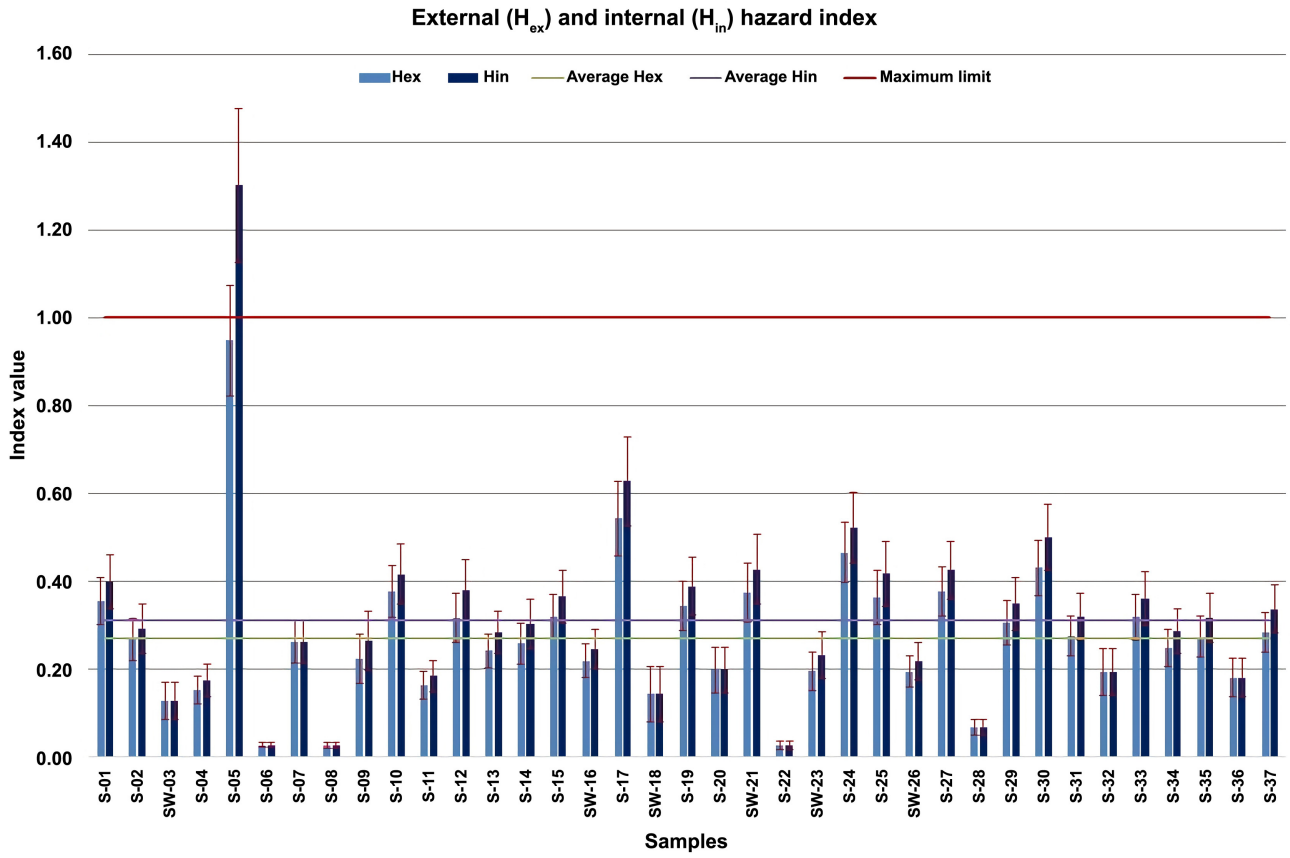

Figure 2. External (H_{ex}) and internal (H_{in}) hazard index with compared to allowable limit.

where, C_{Ra}, C_{Th} and C_K are the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in Bq·kg^{-1} respectively. The H_{ex} must not exceed the limit of unity for the radiation hazard to be negligible. As well as, the H_{in} must also be less than unity to have minimal hazardous effect of radon and its progeny to the respiratory organs [17]. In our study all of the samples from both soil and solid waste category having the H_{ex} bellow the unity and only one soil sample S-05 shows the H_{in} value 1.30 ± 0.181, which is higher than unity. Nevertheless, the average of H_{ex} and H_{in} is still within limit. Figure 2 is representing the analysis and result of these indices.

4. Conclusion

The soil and solid waste are nearby the industries in Nasirabad industrial area. Chattogram was collected and investigated through determining the activity concentration of terrestrial radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) using HPGe

gamma ray spectroscopy. No trace of anthropogenic radionuclide (^{137}Cs) was detected in any of the 37 samples *i.e.*, this area is free from unwanted radioactive contamination. The solid waste samples are containing those primordial radionuclides in a noticeably low amount compared to other soil samples. This may due to the source of origin of these two category samples. Besides this, the dose rate from the samples was also determined, few samples show a slightly higher value compared to the world average. The indoor and outdoor annual effective dose equivalent was also studied. In this case, it was clearly found that the average result was below the safety limit except three samples having elevated value. Average of Radium equivalent activity concentration was found below the recommended level, which sounds good. The external, internal hazard index, and activity concentration index value were also measured for further evaluation. It's seen that the averages of these indices are lower than the allowed safety level. The studied soil and solid waste samples from a growing industrial area will help to establish a baseline radiological data for further environmental safety precaution.

Acknowledgements

Authors are thankful to staff and authority of Atomic Energy Centre, Chattogram for their undisputable support to complete this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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