J. Bangladesh Acad. Sci., Vol. 43, No. 2, 169-180, 2019
DOI: https://doi.org/10.3329/jbas.v43i2.45738

THE ACTIVITY CONCENTRATION OF RADIONUCLIDES (^{226}Ra, ^{232}Th AND ^{40}K) IN SOIL SAMPLES AND ASSOCIATED HEALTH HAZARDS IN NATORE, KUSHTIA AND PABNA DISTRICT OF BANGLADESH

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ABSTRACT

The study has been carried out to measure the activity concentration of natural and anthropogenic radionuclides in fifteen(15) soil samples of Natore, Kushtia and Pabna district, which are around the 30 km peripheral area of Rooppur Nuclear Power Plant, by gamma ray spectrometry system using a High Purity Germanium (HPGe) detector. It is found that the activity concentration of ^{226}Ra, in the collected sample was from 3.52 Bq/kg to 28.5 Bq/kg with the average value of 12.42 Bq/kg. For ^{232}Th, the range was from 4.18 Bq/kg to 34.5 Bq/kg with the average value of 12.6 Bq/kg. Finally, the activity concentration of ^{40}K, in the collected sample was in the range of 84 Bq/kg to 345 Bq/kg, and the average value was 198.9 Bq/kg. The absorbed dose rate (D) was found to be in the range of 4.59 nGy/h to 40.93 nGy/h with the mean value 21.3 nGy/h. The annual effective dose (E) was in the range of 0.006 mSv/yr to 0.152 mSv/yr with an average of 0.033 mSv/yr. The radium equivalent activity was in the range from 10.02 Bq/kg to 89 Bq/kg with an average of 44.99 Bq/kg. The external hazard index (H_{ex}) was found to be in the range of 0.027 to 0.242 with the mean value of 0.121 and the internal hazard index (H_{in}) was found to be in the range of 0.044 to 0.302 with the mean value of 0.156. All the values are much below the recommended limit by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 35 Bq/kg for ^{226}Ra, 30 Bq/kg for ^{232}Th and 400 Bq/kg for ^{40}K. According to international and national regulation, the annual dose to members of the public, $1\ mSvy^{-1}$ and H_{ex} & H_{in} must be lower than unity. Moreover, no artificial radioactivity was found in the soil samples of this study area. This research concludes that the found values are within the permissible limits as required by the Nuclear Safety and Radiation Control(NSRC) Rules-1997 of Bangladesh and International Atomic Energy Agency(IAEA) Safety Standards- General Safety Requirements (GSR): Part-3.

Keywords: Gamma Ray Spectrometry, High Purity Germanium (Hpge) Detector, Activity Concentration, Absorbed Dose Rate, Annual Effective Dose, Radium Equivalent Activity, External Hazard Index, Internal Hazard Index, Natore, Kushtia, Pabna , Rooppur NPP, Bangladesh.

INTRODUCTION

Radionuclides are unstable isotopes, which undergo radioactive decay i.e. they emit alpha particles, beta particles and gamma rays. Some radionuclides occur naturally in air, rocks, soils and plants and some are produced artificially as in nuclear weapon testing. The vast majority of radioisotopes are artificially produced. Uranium, Thorium and Radium are the best-known naturally occurring radioactive element. Nuclides radiation affects the emulsion of photographic film, ionize surrounding air molecules, make certain compounds fluorescent,

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and have certain special biological effects. They undergo radioactive decay (Hurst and Turner, 1995). The emission of a particle or energy from the nucleus of radionuclide is called radiation. There are mainly three types of radiation called alpha (α), beta (β) and gamma (γ). Although these three kinds have penetrating power but gamma (γ) rays are the most penetrating, requiring several centimeters of lead to absorb them (Eisenbud and Gesell, 1997). All the three kinds of radiation cause health hazards like somatic destruction and genetic destruction or disorders, leukemia, eye cataracts, various forms of cancer and exert mutagenic effects on human. The hazard is greatest if the radionuclide enter the body through the intake of contaminated food, water or air (UNSCEAR 2000a). There are many sources of radiation and radioactivity in the environment. Gamma radiation emitted from naturally occurring radionuclide also called as terrestrial background radiation represents the main extent sources of irradiation on the human body. Predominant part of the radio activity of soil and sediment devices from the decay of the primordial radionuclides ^{238}U, ^{235}U, ^{232}Th, and their numerous decay products.^{87}Rb and ^{40}K and also significant amount of manmade radio nuclides ^{137}Cs and ^{90}Sr may also be present in the soil. Once present in the environment, these radionuclides, whether natural or artificial are available for uptake by plants and animals and as a result make their way into the food chain, which affect human both implicitly and explicitly (Kabir K.A. *et al*., 2009). Because of natural and artificial processes, radionuclides may accumulate and be concentrated in selected areas of the environment. The natural radioactivity of soil 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. Radioactivity of soil is one of the main sources of exposure to human. Hence, it is important to know its distribution, gamma radiation from radionuclides, which are characterized by half-lives comparable to the age of the earth, such as ^{40}K and radionuclides from ^{238}U and ^{232}Th series. Their decay products, ^{226}Ra (^{238}U-chain), ^{228}Ra (^{232}Th-chain) and non-chained (^{40}K) represent the main sources of radiation to the human (Abusini *et al.,* 2008).

Detection of radioactivity, analysis and interpretation of data collected from the radioactive samples require advanced devices and techniques. The gamma-ray spectrometry, used for low background radio analysis, has been one of the most popular techniques in recent times. There are three types of gamma ray detectors that can be used for gamma ray analysis: thallium doped sodium iodide crystal NaI (Tl) scintillation detector, lithium drifted crystal of purified germanium detector, and High-Purity Germanium (HPGe) detector. Among them, HPGe detector is the most sensitive and efficient device which is widely used in determining activity of radionuclides from higher order down to pCi level (Goulding FS *et al*., 1966) and Hansen WL *et al*., 1971). In this work, we HPGe- gamma ray detector has been used to analyze collected soil samples having a wide range of radioactivity

EXPERIMENTAL PROCEDURE

Area of Study

This study was carried out in the 30km radius area from the RNPP. This area includes roughly three districts. Samples were collected from both disturbed and undisturbed soil. A total of 15 soil samples from different area were collected for laboratory analysis (Table 1). Natural radionuclides were analyzed at the Health Physics Division of Atomic Energy Centre Dhaka (AECD).

MATERIAL AND METHODS

Natural radionuclides were measured by means of Gamma Spectrometry using a High Purity Germanium (HPGe) detector. Sample preparation is recognized as the major source of errors and if not done properly, may affect the

final results. Therefore, close attention was paid to every sample to avoid cross-contamination, heavy metal and radionuclide losses amongst other precautions. The collected soil samples were first spread out on plastic sheets and allowed to air dry for 2-3 days. The soil samples were then heated in an electric oven at 110ºC for up to 24 hours to remove moisture further and thereafter placed in an electric furnace at 350ºC for 48 hours to ash the plant remains. All the samples were then passed through a sieve of mesh size 2 mm to obtain a homogenous sample matrix (IAEA, 1989). Each of the samples was weighed using an electronic balance, model no KD160, TANITA. The samples were then packed and sealed in plastic containers for 28 days before gamma spectrometric measurements. Sealing establishes secular equilibrium among the progenies of ^{238}U and ^{232}Th series by ensuring that there is no radon gas leakage due to the decay of ^{226}Ra.

Table 1: GPS location of the sampling points.

Sl	Local Name	Sample ID	Lattitude	Longitude
01.	Pakshi	PAK-S-01	24.0695N	89.0355E
02.	Pakshi	PAK-S-02	24.0703N	89.0317E
03.	Sahapur	SAH-S-03	24.0633N	89.0689E
04.	Sahapur	SAH-S-04	24.0350N	89.1003E
05.	Dashuria	DAS-S-05	24.0484N	89.1356E
06.	Dashuria	DAS-S-06	24.0432N	89.1492E
07.	Hemayetpur	HEM-S-07	24.0074N	89.2104E
08.	Hemayetpur	HEM-S-08	24.0205N	89.1907E
09.	Veramara	VER-S-09	24.0551N	89.0126E
10.	Veramara	VER-S-10	24.0576N	89.0176E
11.	Veramara	VER-S-11	24.0582N	89.0185E
12.	Lalpur	LAL-S-12	24.1770N	88.9640E
13.	Lalpur	LAL-S-13	24.1620N	88.0021E
14.	Muladuli	MUL-S-14	24.1590N	89.1380E
15.	Muladuli	MUL-S-15	24.1572N	89.1401E

Efficiency Calibration of the Detector

The efficiency calibration of the detector was performed by standard sources of solid and liquid matrices prepared using ^{226}Ra. Identical containers were used for the measurement of the samples, e.g. 250 mL plastic container for solid samples. The preparation process of standard sources had been reported elsewhere (M.A. Usif *et al.*, 2008). The detector efficiency calibration curve as a function of energy for solid matrix is shown in Fig.1. The energy calibration of the detector was performed by ^{137}Cs and ^{60}Co point sources.

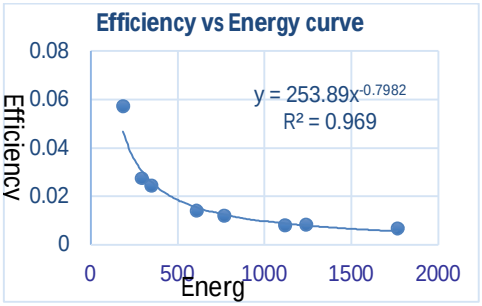

Fig. 1: Efficiency calibration graph.

Calculation of Activity Concentrations of Soil Sample

The radionuclide contents and their activity levels in the samples were measured using a

calibrated HPGe detector. The activity concentration (*A*) of each radionuclide in the samples was determined by using the net count (*cps*) (found by subtracting the background counts from the gross counts with same counting time under the selected photo peaks), weight of the sample, the photo-peak efficiency and the gamma intensity at a specific energy as (G. F. Knoll,1998):

$$A = \frac{cps}{E \times I \times W} \quad (1)$$

Where *A* is the activity in Bq/kg; cps = the net gamma counts per second= cps for sample – cps for background, E = the efficiency of the detector at energy E (keV); I= Absolute intensity of the gamma ray and W = the dry mass of the sample.

Error in Radioactivity Measurement

The disintegration of radionuclide is a random process, only an estimate of the true activity of a sample can be obtained. Factors such as confidence limit and the sample counting error are all dependent on counting time. When a large number of samples with low level activities have to be assessed, it is important to utilize the time available in the most efficient manner. The percentage of sample counting error for the radioactivity measurement is found out with the help of the following relation (Monira *et al.*, 2005).

$$\sigma = \sqrt{\frac{N_t}{T_t^2} + \frac{N_b}{T_b^2}} \quad (2)$$

Where, σ is the standard deviation; N_t is the number of counts for samples; N_b the counts for the background; T_t the counting time for N_t and T_b the counting time for N_b.

Calculation of absorbed dose rate

Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the soil. The absorbed dose rate in air 1 meter above the ground surface due to the radionuclides ^{238}U, ^{232}Th and ^{40}K in soil was estimated using the formula given in UNSCEAR 2000.

$$D(nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.042A_K \quad (3)$$

Where, A_{Ra}, A_{Th} and A_K are specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg.

Calculation of Outdoor Annual Effective Dose

The absorbed dose rate was converted into annual effective dose equivalent by using a conversion factor of 0.7 SvGy-1 recommended by the UNSCEAR 2000 and 0.2 for the outdoor occupancy factor by considering that the people on the average, spent 20% of their time in outdoors [K. Debertin *et al.*, 1988] . The effective dose of public due to natural activity in the soil samples was calculated by: $E\ (mSvyr^{-1}) = D \times 24 \times 365.25 \times 0.2 \times 0.7 \times 10^{-6}$ (4)

Calculation of Radium Equivalent Activity

The radionuclides ^{226}Ra, ^{232}Th and ^{40}K are not homogeneously distributed in soil. The inhomogeneous distribution of naturally occurring radionuclides is due to disequilibrium between 226Ra and its decay products. For uniformity in exposure estimates, the radionuclide concentrations are defined in terms of 'Radium equivalent activity'(Ra_{eq}) in $Bqkg^{-1}$. This allows comparison of the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K according to Beretka and Mathew (1985) as follows:

$$Ra_{eq}\ (Bqkg^{-1}) = A_{Ra} + 1.43\ A_{Th} + 0.077A_K \quad (5)$$

Where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively in $Bqkg^{-1}$.

Calculation of External and Internal Hazard Index

Local soil of the area is used for the construction of houses and also for agricultural purposes. These soils may contribute to the external gamma dose rates to the public. The external hazard index (Hex) is the indoor radiation dose rate due to the external exposure to gamma radiation in construction materials of dwelling which is calculated by Beretka *et al.* (1985).

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

On the other hand, the internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and its short-lived progeny and is given by the the following formula [1985 Beretka *et al.*]:

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

Where, A_{Ra}, A_{Th} and A_K have the same meanings as in equation (3), and (5).

The value of Hex must be lower than unity in order to keep the radiation hazard insignificant.

RESULTS AND DISCUSSION

In this study, total fifteen (15) soil samples were collected from three different districts namely Pabna, Kushtia and Natore to investigate the natural radioactivity concentration using gamma spectrometry. The absorbed dose, annual effective dose, Radium equivalent activity, external hazard index and internal hazard index were calculated to assess any health risk associated with the soil.

Radioactivity concentrations of daughter nuclides in soil

To investigate the natural radioactive concentration using gamma spectrometry, fifteen (15) soil samples were collected. Radioactivity concentrations of daughter nuclides in soil from three different places are given in Tables 2-4.

Table 2. Activity concentration of daughter nuclides for soil from Pabna.

Radio nuclides	Energy (keV)	Activity Concentration of Soil Sample from Pabna (Bq/kg)									
		PAK-S-01	PAK-S-02	SAH-S-03	SAH-S-04	DAS-S-05	DAS-S-06	HEM-S-07	HEM-S-08	MUL-S-14	MUL-S-15
^{212}Pb	238.63	5.13	58.4	5.63	47.45	10.52	11.43	5	2.78	5.1	12.56
^{214}Pb	295.21	26.36	19.55	23.4	6.74	12.22	0	9.81	11.6	4.57	10.42
^{214}Pb	351.92	1.96	14.87	28.5	4.59	4.15	10.77	3.72	8.89	6.21	4.8
^{208}Tl	583.14	9.13	32.92	23.3	8.52	16.85	20.14	13.24	0	24.74	26.7
^{214}Bi	609.31	0	35.28	8.45	13.2	3.63	39.84	4.33	0	8.35	14.73
^{228}Ac	911.07	26.4	21.2	0	0	4.22	50.43	4.96	7.01	11.36	7.59
^{228}Ac	969.11	0	25.6	0	2.13	12.36	37.94	9.07	11.5	19.53	19.92
^{214}Bi	1120.3	0	15.08	0	6.18	11.87	33.84	5.98	1.87	38.18	7.62
^{40}K	1460.8	169	235	182	128	84	225	132	345	299	291

Table 3. Activity concentration of daughter nuclides for soil from KUSHTIA and Natore.

Radionuclides	Energy (keV)	Activity Concentration of Soil Sample from Kushtia				Activity Concentration of Soil Sample from Natore (Bq/kg)
		VER-S-09	VER-S-10	VER-S-11	LAL-S-12	LAL-S-13
^{212}Pb	238.63	1.41	3.24	5.42	1.11	13.04
^{214}Pb	295.21	10.63	5.31	3.69	0.79	18.69
^{214}Pb	351.92	8.25	2.8	1.29	0	8.50
^{208}Tl	583.14	10.16	8.99	0.75	7.25	5.46
^{214}Bi	609.31	7.77	7.57	15.26	0	5.59
^{228}Ac	911.07	11.99	0	4.78	0	15.32
^{228}Ac	969.11	9.78	0	10.84	68.91	10.68
^{214}Bi	1120.3	0	1.74	3.92	2.88	10.15
^{40}K	1460.8	152	268	256	191	94

Table 4. The activity concentration of parent nuclides for soil collected from Pabna

Sample code	Activity concentration(Bq/kg)in soil		
	^{226}Ra	^{232}Th	^{40}K
PAK-S-01	3.52±1.03	4.54±1.17	101.79±7.53
PAK-S-02	22.14±2.32	34.53±2.41	235±13.78
SAH-S-03	28.5±2.42	14.48±1.16	182±12.42
SAH-S-04	8.28±1.63	14.5±1.45	128.05±11
DAS-S-05	7.96±1.2	10.98±1.56	84±8.99
DAS-S-06	26±2.37	29.98±2.43	225±21.11
HEM-S-07	5.96±1.13	8.07±1.26	132±12.35
HEM-S-08	7.97±1.49	7.1±1.3	345±16.65
MUL-S-14	14.47±1.81	15.18±1.73	299±40.38
MUL-S-15	9.63±1.59	16.6±1.81	291±13.96
Average	13.44±1.69	15.59±1.62	202.28±15.81
Minimum value	3.52±1.03	4.54±1.17	84±8.99
Maximum value	28.5±2.42	34.53±2.41	345±16.65
World average value	35	30	400

Radioactivity concentration of parent nuclides in soil.

Radioactivity concentration of parent nuclides in soil from Pabna

The activity concentration of ^{226}Ra for soil of Pabna were found within the range of 3.52±1.03 Bq/kg to 28.5±2.42 Bq/kg (Table 4). The average value for ^{226}Ra for soil of Pabna is 13.44±1.69Bq/kg which is below the world average value 35 Bq/kg [UNSCEAR 2000].

The average activity concentration of ^{232}Th in soil from Pabna was 15.59±1.62Bq/kg within a range from 4.54±1.17 to 34.53±2.41 Bq/kg. This is approximately 50% of the world average value 30 Bq/kg [UNSCEAR 2000].

The radioactivity concentration of ^{40}K in soil from Pabna was in the range from 84±8.99to 345±16.65Bq/kg with an average value of 202.28±15.81 Bq/kg which is 50% of the world average value 400 Bq/kg [UNSCEAR 2000].

Radioactivity concentration of parent nuclides in soil from Kushtia

Table 5. The activity concentration of parent nuclides for soil collected from Kushtia

Sample code	Activity concentration(Bq/kg)in soil		
	^{226}Ra	^{232}Th	^{40}K
VER-S-09	9.28±1.4	8.33±1.54	152±11.6
VER-S-10	4.57±1.29	6.115±0.97	268.2±13.99
VER-S-11	5.05±1.31	5.45±1.36	256±14.34
Average	6.3±1.33	6.63±1.29	225.4±13.31
Minimum value	4.57±1.29	5.45±1.36	152±11.6
Maximum value	9.28±1.4	8.33±1.54	268.2±13.99
World aver. value	35	30	400

The activity concentration of ^{226}Ra for soils of Kushtia were found to be within the range of 4.57±1.29 to 9.28±1.4 Bq/kg (Table 5). The average value for ^{226}Ra for soils of Kushtia 6.3±1.33Bq/kg which is 18% of the world average value 35 Bq/kg [UNSCEAR 2000].

The average activity concentration of ^{232}Th in soil from Kushtia was 6.63±1.29 Bq/kg within a range from 5.45±1.36 to 8.33±1.54 Bq/kg. This is approximately 23% of the world average value 30 Bq/kg [UNSCEAR 2000]. The radioactivity concentration of ^{40}K in soil from Kushtia was in the range from 152±11.6 to 268.2±13.99 Bq/kg with an average value of 225.4±13.31 Bq/kg which is 57% of the world average value 400 Bq/kg [UNSCEAR 2000].

The highest activity concentration of ^{226}Ra was found in sample VER-S-09 and the lowest was in VER-S-10. For ^{232}Th, highest values was found in VER-S-09 and the lowest value was in VER-S-11 and for ^{40}K, highest result was

obtained in VER-S-10 and lowest values was obtained in VER-S-09.

Radioactivity concentration of parent nuclides in soil from Natore

The activity concentration of ^{226}Ra for soil of Natore were found within the range of 12±1.36 to 21±2.09 Bq/kg (Table 6). The average value for ^{226}Ra for soil of Pabna is 16.5±1.725 Bq/kg which is below 50% of the world average value 35 Bq/kg [UNSCEAR 2000].

Table 6. The activity concentrations of natural radionuclides for soil collected from Natore

Sample code	Activity concentration(Bq/kg) in soil		
	^{226}Ra	^{232}Th	^{40}K
LAL-S-12	21±2.09	4.19±0.97	191±12.56
LAL-S13	12±1.36	9.86±1.49	94±9.24
Average	16.5±1.725	7.025±1.23	142.5±10.9
Minimum value	12±1.36	4.19±0.97	94±9.24
Maximum value	21±2.09	9.87±1.49	191±12.56
World average value	35	30	400

The average activity concentration of ^{232}Th in soils from Natore was 7.025±1.23Bq/kg within range of 4.19±0.97 to 9.86±1.49Bq/kg. It is below 25% of the world average value 30 Bq/kg [UNSCEAR 2000]. The radioactivity concentration of ^{40}K in soils from Natore to the range from 94±9.24 to 191±12.56Bq/kg with an average value of 142.5±10.9Bq/kg. This average value is below 50% of the world average value 400 Bq/kg [UNSCEAR 2000].

Considering all the 15 soil samples collected from Pabna, Kustia and Natore, it is observed that the activity concentration of ^{226}Ra was from 3.52 Bq/kg to 28.5 Bq/kg with the average value of 12.42 Bq/kg. For ^{232}Th, the range was from 4.18 Bq/kg to 34.5 Bq/kg with the average value of 12.6 Bq/kg. Finally, the activity concentration of ^{40}K was in the range of 84 Bq/kg to 345 Bq/kg, and the average value was 198.9 Bq/kg.

Absorbed Dose Rate in Soil Samples

There are fifteen (15) Soil Samples from different locations around 30 km of Rooppur Nuclear Power Plant have been studied for the assessment of absorbed dose rate calculation.

Absorbed dose Rate in Soil Samples from Pabna

Table 7. Absorbed dose Rate(n Gyh-1) for soil samples collected from Pabna.

Sample code	^{226}Ra	^{232}Th	^{40}K	Absorbe dose rate, D(n Gyh^{-1})
PAK-S-01	3.52±1.03	4.54±1.17	101.79±7.53	4.593
PAK-S-02	22.14±2.32	34.53±2.41	235±13.78	40.93
SAH-S-03	28.5±2.42	14.48±1.16	182±12.42	29.55
SAH-S-04	8.28±1.63	14.5±1.45	128.05±11	17.96
DAS-S-05	7.96±1.2	10.98±1.56	84±8.99	13.83
DAS-S-06	26±2.37	29.98±2.43	225±21.11	38.97
HEM-S-07	5.96±1.13	8.07±1.26	132±12.35	13.17
HEM-S-08	7.97±1.49	7.1±1.3	345±16.65	22.46
MUL-S-14	14.47±1.81	15.18±1.73	299±40.38	28.41
MUL-S-15	9.63±1.59	16.6±1.81	291±13.96	26.69
Average				23.65

There was ten soil samples collected from Pabna. The highest and lowest absorbed dose rate are 4.59 (n Gyh^{-1}) in PAK-S- 01 and 40.93 ($nGyh^{-1}$) in PAK-S-02. The average value 23.65(n Gyh^{-1}) is 2.32 times lower than world average value [UNSCEAR 2000].

Absorbed dose Rate in soil samples from Kushtia

Table 8. Absorbed dose Rate(n Gyh-1) for soil samples from Kushtia

Sample code	^{226}Ra	^{232}Th	^{40}K	Absorbed dose rate, D(n Gyh^{-1})
VER-S-09	9.28±1.4	8.33±1.54	152±11.6	15.7
VER-S-10	4.57±1.29	6.115±0.97	268.2±13.99	17.06
VER-S-11	5.05±1.31	5.45±1.36	256±14.34	16.37
Average				16.3

Three soil samples collected from Kushtia. The highest and lowest absorbed dose rate were 17.06 (n Gyh^{-1}) in VER-S-10 and 15.7(n Gyh^{-1}) IN VER-S-09. The average value 16.3($nGyh^{-1}$) is 3.3 times lower than the world average [UNSCEAR 2000].

Absorbed dose Rate in soil samples from Natore

Table 9. Absorbe dose rate (n Gyh-1) for soil samples from Natore

Sample code	^{226}Ra	^{232}Th	^{40}K	sorbed se rate, $nGyh^{-1}$)
LAL-S-12	21±2.09	4.19±0.97	191±12.56	18.93
LAL-S-13	12±1.36	9.86±1.49	94±9.24	15.44
Average				17.185

There were two soil samples collected from Natore. The highest and lowest absorbed dose rate are 15.44 ($nGyh^{-1}$) in LAL-S-13 and 18.93($nGyh^{-1}$) in LAL-S-12. The average value 17.18($nGyh^{-1}$) is 3.2 times lower than world average [UNSCEAR 2000].

Considering all the 15 soil samples collected from Pabna, Kustia and Natore, the absorbed dose rate (D) was found to be in the range of 4.59 nGy/h to 40.93 nGy/h with the mean value 21.3 $nGyh^{-1}$.

Annual Effective dose in Soil Samples

The annual effective dose for public from all the samples was calculated. The results are given below:

Annual Effective Dose for public from Soil Samples at Pabna

Table 10. Annual Effective Dose (mSv/yr) for Pabna.

Sample ID	Annual Effective
PAK-S-01	0.0056
PAK-S-02	0.0502
SAH-S-03	0.036
SAH-S-04	0.022
DAS-S-05	0.0169
DAS-S-06	0.1522
HEM-S-07	0.0161
HEM-S-08	0.0275
MUL-S-14	0.0348
MUL-S-15	0.0327
Average	**0.0394**

From the table, it is seen that the annual effective dose for public from Pabna is below the world average value. The highest value of annual effective dose is 0.1522 mSv/yr for DAS-S-06 and the lowest value is 0.0056 mSv/yr for PAK-S-01.

Annual Effective Dose in Soil Samples from Kushtia

Table 11: Annual Effective Dose (mSv/yr) for Kushtia

Sample ID	Annual Effective Dose E(mSv/yr)
VER-S-09	0.019
VER-S-10	0.0209
VER-S-11	0.02
Average	0.0199

The annual effective dose for Kushtia ranges from 0.019 mSv/yr to 0.0209 mSv/yr with an average value of 0.0199 mSv/yr which is below the world average value [UNSCEAR 2000].

Annual Effective Dose (mSv/yr) for public from Soil Samples at Natore

Table 12. Annual Effective Dose for Natore

Sample ID	Annual Effective Dose E (mSv/y)
LAL-S-12	0.023
LAL-S-13	0.0189
Average	0.02095

The annual effective dose for Kushtia ranges from 0.0189 mSv/yr to 0.023 mSv/yr with an average value of 0.02095 mSv/yr which is below the world average value [UNSCEAR 2000].Considering all the 15 soil samples collected from Pabna, Kustia and Natore, the annual effective dose (E) was found to be in the range of 0.006 mSv/yr to 0.152 mSv/yr with an average of 0.033 mSv/yr.

Radium Equivalent Activity in Soil Samples

Radium equivalent activity of the 15 soil samples was calculated. The results are given below:

Radium Equivalent Activity in Soil Samples from Pabna

Table 13. Radium Equivalent activity for Pabna

Radium Equivalent activity (Bq/kg) for Pabna	
Sample ID	**Radium Equivalent activity**
PAK-S-01	10.02
PAK-S-02	89.57
SAH-S-03	63.2
SAH-S-04	38.87
DAS-S-05	30.12
DAS-S-06	84.795
HEM-S-07	27.66
HEM-S-08	44.68
MUL-S-14	58.943
MUL-S-15	55.77
Average	50.36

The Radium Equivalent Activity for Pabna ranges from 10.02 Bq/kg in PAK-S-01 to 89.57 Bq/kg in PAK-S-02 with an average value of 50.36 Bq/kg which is below the world average value [UNSCEAR 2000].

Radium Equivalent Activity in Soil Samples from Kushtia

Table 14. Radium Equivalent Activity (Bq/kg) for Kushtia

Sample ID	Radium Equivalent activity (Bq/kg)
VER-S-09	32.89
VER-S-10	33.96
VER-S-11	32.55
Average	33.13

The Radium Equivalent Activity for Kushtia ranges from 32.55 Bq/kg in VER-S-11 to 33.96 Bq/kg in VER-S-10 with an average value of 33.13 Bq/kg which is below the world average value [UNSCEAR 2000].

Radium Equivalent Activity in Soil Samples from Kushtia

Table 15. Radium Equivalent Activity (Bq/kg) for Natore.

Sample ID	Radium Equivalent activity (Bq/kg)
LAL-S-12	38.56
LAL-S-13	33.3
Average	35.93

The Radium Equivalent Activity for Natore ranges from 33.3 Bq/kg in LAL-S-13 to 38.56 Bq/kg in LAL-S-12 with an average value of 35.93 Bq/kg which is below the world average value [UNSCEAR 2000].

Considering all the 15 soil samples collected from Pabna, Kustia and Natore, the radium equivalent activity was found to be in the range of 10.02 Bq/kg to 89 Bq/kg with an average of 44.99 Bq/kg.

External and Internal Radiation Hazard Indices

Table 16. External and Internal Radiation Hazard Indices for Pabna

Sample ID	H_{ex}	H_{in}
PAK-S-01	0.027	0.0437
PAK-S-02	0.2418	0.3017
SAH-S-03	0.1707	0.2477
SAH-S-04	0.1049	0.1273
DAS-S-05	0.0813	0.1028
DAS-S-06	0.229	0.2990
HEM-S-07	0.0747	0.0908
HEM-S-08	0.1206	0.1422
MUL-S-14	0.1579	0.1989
MUL-S-15	0.1506	0.1766
Average	0.121	0.156

Both the external (H_{ex}) and internal (H_{in}) hazard index are less than unity for all the soil samples from Pabna.

Table 17. External and Internal Radiation Hazard Indices for Kushtia

Sample ID	H_{ex}	H_{in}
VER-S-09	0.088	0.113
VER-S-10	0.0917	0.1040
VER-S-11	0.0879	0.1015
Average	0.0892	0.1061

The external (H_{ex}) and internal (H_{in}) hazard index are less than unity for all the soil samples from Kushtia.

Table 18. External and Internal Radiation Hazard Indices for Natore

Sample ID	H_{ex}	H_{in}
LAL-S-12	0.1041	0.1693
LAL-S-13	0.09	0.1224
Average	0.0971	0.1459

The external (H_{ex}) and internal (H_{in}) hazard index are less than unity for all the soil samples from Natore.

Considering all the 15 soil samples collected from Pabna, Kustia and Natore, the external hazard index (H_{ex}) was found to be in the range of 0.027 to 0.242 with the mean value of 0.121 and the internal hazard index (H_{in}) was found to be in the range of 0.044 to 0.302 with the mean value of 0.156.

Comparison with Different country with present study

A comparison of the average activity concentration (in Bq kg^{-1}) in soil samples under investigation with those in other countries

Table 19. Comparison of the average activity concentration with other countries (in Bq kg^{-1})

Country	^{226}Ra	^{232}Th	^{40}K	Reference
Jordan	49.9	26.7	291.1	[Al-Hamameh I *et al.]*
Saudi Arabia	14.5	11.2	225.0	[Alaamer A *et al.*]
Iran	28.5	53.7	490.9	[Rafique M *et al.*]
Turkey	17.6	21.1	297.5	[Degerlier M *et al.*]
Malaysia	57.0	68.0	427.0	[Almayahi B *et al.]*
Pakistan	45.0	67.0	878.0	[Khan H *et al.*]
China	26.0	49.0	440.0	[Wang Z *et al.*]
Libya	7.5	4.5	28.5	[El-Kameesy SU *et al.*]
Hungary	33.3	32.1	418.0	[Papp Z *et al.*]
Oman	14.4	10.0	158.2	[Saleh IH *et al.*]
Ghana	13.6	24.2	162.1	[Faanu A *et al.*]
Thailand	67.7	45.0	213.1	[Kessaratikoon P *et al.*]
Pabna	13.44	15.59	202.28	Present Study
Kushtia	6.3	6.63	225.3	Present Study
Natore	16.5	7.025	142.5	Present Study
Worldwide	35	30	400	[UNSCEAR 2000a]

Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in all 15 soil samples were found below the world

average value. Absorbed dose rate, annual effective dose rate, radium equivalent activity, external and internal hazard index were also below the average value mentioned in UNSCEAR report [UNSCEAR 2000].

CONCLUSION

To inspect the radiation level of the environment, around 30 km peripheral area of Rooppur Nuclear Power Plant, 15 soil samples were collected. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K and associated health hazards in the soil samples were investigated in this present study. The natural radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K were found lower than the world average value. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil sample collected from Pabna were 13.44±1.69 Bq/kg, 15.59±1.62 Bq/kg and 202.28±15.81 respectively, in Kushtia, 6.3±1.33.Bq/kg 6.63±1.29 Bq/kg and 225.3±13.31 Bq/kg respectively and in Natore, 16.5±1.725 Bq/kg, 7.025±1.23Bq/kg and 142.5±10.9 Bq/kg respectively. The activity concentrations of ^{226}Ra, ^{232}Th and^{40}K in the soil were not uniform and varied from soil to soil and location to location, depending upon the geological characters of the area under study.

The absorbed dose rate in the soil samples were from 4.59 nGy/h to 40.93 nGy/h with an average value of 21.33 nGy/h. The annual effective dose rate for public on the on the average, spent 20%, was found in the range of 0.0056 mSv/yr to 0.1522 mSv/yr with a mean value of 0.033 mSv/yr. The radium equivalent activity was in the range from 10.02 Bq/kg to 89 Bq/kg with an average of 44.99 Bq/kg. The average external hazard index was found to be 0.121 and the average internal hazard index was 0.156. All the values are much below the suggested limit by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 35 Bq/kg for ^{226}Ra, 30 Bq/kg for ^{232}Th and 400 Bq/kg for ^{40}K . According to NSRC Rules-1997 as the annual dose to members of the public, $1\ mSvy^{-1}$ and H_{ex} & H_{in} must be lower than unity. In conclusion, the found values within the limits recommended by the Nuclear Safety and Radiation Control(NSRC) Rules-1997 of Bangladesh and International Atomic Energy Agency(IAEA) Safety Standards- General Safety Requirements (GSR): Part-3.

There is further scope to study more environmental samples like water and plants in order to get a more elaborate view of the radiation level in environment. All the values found are much below the world average value. Moreover, no artificial radioactivity was found in the soil samples of this study area. This means that the radiation level of the soil samples in the study area does not pose any health risk currently. So, there is a need for continuous environmental monitoring program in order to determine any change due to artificial radioactivity releasing from the nuclear installation in case of incident/accident. This study will be useful for baseline data for the assessment of human radiation exposure from natural environment.

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(Received revised manuscript on 31 December 2019)