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Natural Radioactivity, Radon Exhalation Rates and Radiation Doses in the Soil Samples Collected from the Vicinity of Kolaghat Thermal Power Plant, West Bengal, India

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Natural radioactivity has been determined by means of a highly efficient thallium-doped sodium iodide detector in soil sample from surface of from vicinage of "Kolaghat Thermal Power Plant" The activity concentration (specific activity) is found to vary from 23.70 ± 3.41 to 33.90 ± 4.33 Bqkg^{-1} for ^{226}Ra, from 6.67 ± 2.01 to 21.60 ± 2.11 Bqkg^{-1} for ^{232}Th and that for ^{40}K from 461.01 ± 66.16 to 610.25 ± 80.87 Bqkg^{-1} with expected value of 29.26 ± 3.50, 4.86 ± 2.03 and 517.53 ± 71.61 Bqkg^{-1} of Radium-226, Thorium-232 and Potassium-40 correspondingly. The radon exhalation rates were also computed from all samples using the "Sealed Can Technique". The activity due to radon fluctuates from 47.9 ± 6.2 to 157.6 ± 11.3 Bqm^{-3} having an arithmetic mean of 89.3 ± 7.9 Bqm^{-3}. The surface exhalation rate and mass exhalation rates were estimated to fluctuate from17.3 ± 2.2 to 56.8 ± 4.1 mBqm^{-2}h^{-1} with an expectation of 32.1 ± 3.0 mBqm^{-2}h^{-1} and from 0.6 ± 0.1 to 2.1 ± 0.2 mBqkg^{-1}h^{-1} averaged out to 1.2 ± 0.1 mBqkg^{-1}h^{-1}respectively. Radiation doses were also calculated in these samples. Indoor and outdoor annual effective doses, Absorbed dose rates, External Hazard index and Indoor inhalation exposure, also known as radon effective dose, was computed and varied from 0.19 to 0.25 mSv y^{-1}, 39.30 to 51.61 nGyh^{-1}, 0.048 to 0.063 mSvy^{-1}, 0.21 to 0.28 and 0.29 to 0.36 and 2.04 to 6.70 μSvy^{-1} respectively. The values which were obtained in this study are found to be well below the allowed permissible limits, so the soil may be used as building construction material.

Keywords: NaI(Tl); Hazard Index; Annual effective dose; Radon activity; Gamma radiation representation level index

1 Introduction

Natural radiation exposures have two main contributors high-energy cosmic rays coming to the earth's atmosphere and radio-nuclides originating inside the earth's crust and are omnipresent through the environment, in addition to the human body itself. Throughout their lives, everyone is constantly exposed to some level of radiation. The world's attention is currently focused on nuclear radiation due to its catastrophic side effects, which can last for decades or even centuries. If an area of land becomes contaminated, the contamination may cause chain reactions[1]. Coal combustion may intensify the natural radiation in the purlieus of the power plant with the emanation of the radionuclides and their daughters in the circumambient ecosphere, such as the surface soil, due to the production of ash. Particularly for Indian power plants, this is a major threat because most of the power plants in India utilise coal having low quality with 5 to 50% of ash content. It has been reported in previous studies that 750 million tons of fly ash are produced annually by thermal power plants worldwide.

Coal combustion by-products contain about 80% of fly ash used in the production of cement, asbestos, bricks, concrete, road construction and production of ceramic and glass ceramic because of its finest structure. It also improves the strength and durability of cement. Besides these benefits of fly ash, it has always been considered one of the major environmental components. Fly ash consists of particles of very fine size (0.5 to 200 μm in size). When fly ash emerges from the stack, it escapes into the atmosphere due to poor emission-controlling devices used in power plants. The tendency of fly ash to absorb trace elements from coal during combustion

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greatly enhances due to its finer structure and the large area of surface[2]. When fly ash is deposited on the soil in nearby areas of thermal power plants by air, it is reasonably possible that these radionuclides can spread into the soil and contaminate the soil in nearby areas. In recent years, many of the research studies focused on estimating soil contamination because of fly ash produced due to coal burning. Some of these studies reported an insignificant radiological impact, while others revealed an incremental concentration of radionuclides in the soil near about Kolaghat thermal power plant. Because of this reason, soil serves as the leading source of continuous exposure to radiation to human beings in surrounding areas as soil contains primordial radionuclides in variable amounts, which contributes to the radiation and radon thoron progeny[3] (UNSCEAR, 1993).

Natural radioactivity is extensively unfurled in the earth's environment and prevails naturally in soil, air, rocks, sand *etc*. Therefore, it becomes quite necessary to calculate the radiation threat to habitats there repeatedly. As soil is commonly used as a building structure material in our country, like for brickwork and fill-up materials, *etc*., estimating natural radioactivity in soil has become an important task as the soil has become a primary touchstone of radiological pollution for the environment. Knowing the concentrations of radioactive materials and emissions from environmental sources is essential for regulating radiation exposure. Because gamma radiation emitted from NORM is the principal extraneous cause of irradiation of the human body[4], measuring natural radioactivity in soil is vitally essential. Humans inhale or consume a variety of radionuclides and their radioactive isotopes that are prevalent all around us, and they are mostly left unprotected from outdoor natural terrestrial radiation that emanates primarily from the earth's upper layer of 30 cm of soil. An estimate of gamma radiation level is required to provide a relevant reference against radiation safety measures and protection. The presence of radioactive nuclides such as Uranium, Thorium, and Potassium in the soil also allows us to determine the source and quantity of their decay products such as thoron, radon and their progenies[5]. This research aims to employ NaI (Tl) gamma spectrometry to assess natural radioactivity from selected soil samples from the Kolaghat coal-fired power plant's nearby locations. Many studies have been carried out to monitor the radiological assessment of coal used in the Kolaghat thermal power plant and from fly ash produced there. But the soil of the selected area still had not been studied for such an impact.

2 study area

A major coal-fired "thermal power plant" in West Bengal, named Kolaghat Thermal Power Plant, has six units of 210MW each making a total capacity of 1260 MW which was commissioned during the time period of 1984 to 1995. It is located approximately 55 km away from Kolkata at Mecheda in the Purba Medinipur district. The following Fig. 1 shows the locations of the study area. The type of soil in this study area mostly contains large amounts of clay; this type of soil is produced due to fine-grained sedimentary rocks such as shale, mudstone and siltstone.

3 Material and Methods

3.1 Collection of Sample and their preparation

We have collected eleven soil samples from surface soil within the locality of the coal-based power plant in Kolaghat (West Bengal). Firstly three samples were assembled at an interval of 300 m distance starting from KTTP, and for the next three, the distance interval was taken to be 500 m and 1000 m for the rest of the samples. All the samples were collected while moving toward Tamluk, and the district headquarter of Mecheda village. The variation of the distance interval between consecutive sample sites is because the spread and distribution of fly ash

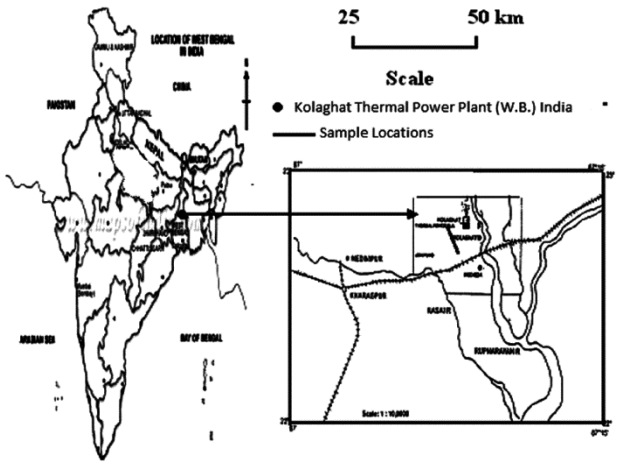

Fig.1 — Location of study area. (*The map is only intended to be used as a visual aid and do not indicate any view on the legal position of any country or territory or the delimitation frontiers or boundaries.)

can vary with the distance. After a heap of soil samples in May 2018, the samples were prepared by drying them to a temperature of 100 °C to efface moisture and then squashed to a triturated powder. All these samples were then passed through a 100-mesh sieve to get homogenised.

3.2 Radon exhalation rates

The exhalation rates for radon were measured in prepared samples by employing the "Sealed Can Technique." In this technique, 11 plastic containers having a diameter of 7 cm with a height of 7.5 cm were airtight for 95 days to secure secular equilibrium between radon and its progenies after filling them with an equal amount (100g) of each soil sample. The plastic containers of particular dimensions are chosen to ensure the similarity of the container with the containers used in calibration experiments[6]. At the top of each container, a film (2 cm x 2 cm) of the "LR-115 type II Solid State Nuclear Track Detector", which is a trade name of cellulose nitrate film manufactured by Kodak Pathe France, was secure like the reactive side of the track detector film can be voluntarily undergo the exposure of the emitted radon aiming to record the tracks of alpha particles by the film. As cellulose nitrate is insensitive to light, X- rays, gamma rays, and electrons hence track recorded on the film are due to emergent alpha particle of energies ranging from 2 to 4 MeV. These alpha particles are radiated by the disintegration of radon in the empty volume of the container. It takes about four hours to secure equilibrium between radon daughters and radon itself, as it is necessary to calculate the equilibrium activity of emitted radon. To do so, 'Can' geometry and exposure time are both important factors. The detectors were removed after 95 days of exposure and etched in NaOH solution having 2.5 Normality at 60 °C in a "constant temperature water bath" for a time period of 90 minutes in order to develop the alpha particle tracks produced on its chemical etching greatly and rapidly attacks the damaged part of the film and slowly removes the surrounding un damaged matrix. An optical compound microscope having magnifying power of 400X was used to tally the resulting alpha particle traces. The radon activity was derived by knowing the track density and a calibration factor of 0.056 $cm^{-2}d^{-1}(Bqm^{-3})^{-1}$ from a previous "calibration experiment" and subsequent recalibrations. The following expression yields the rate of surface exhalation[7,8,10]

$$E_A = \frac{CV\lambda}{A[T+\frac{1}{\lambda}\{e^{-\lambda t}-1\}}} \quad \dots (1)$$

This equation can make alterations to know the mass exhalation rate E_M.

$$E_M = \frac{CV\lambda}{M[T+\frac{1}{\lambda}\{e^{-\lambda t}-1\}}} \quad \dots (2)$$

Where E_M - mass exhalation rate for radon in $Bqkg^{-1}h^{-1}$; E_A- radon surface exhalation rate in units of $Bqm^{-2}h^{-1}$; C- radon exposure in unit of Bq m^{-3} h as measured by track detectorLR-115 type II; V- effective volume of can in m^3; T – time of exposure in hours; A- area of the can in$m^2$and M- mass of the sample.λ being the decay constant for radon in units per hour.

3.3 ^{222}Ra, ^{232}Th and ^{40}K

To calculate the radioactivity content of radium, thorium and potassium abbreviated as "(^{226}Ra, ^{232}Th and ^{40}K)" in soil, the prepared samples were hermetically sealed in plastic containers of dimensions 4.5cm×6cm for about 28 days to make certain the radioactive "Equilibrium" between the radioactive element radon and its daughters. After that, these sealed samples were examined using a highly efficient γ- ray detector. A thallium-activated sodium iodide detector produces a small flash of light known as scintillation when scintillator electrons get excited by the incident gamma ray. The produced scintillations are converted into an electrical pulse by the photomultiplier tube on which the detector crystal is mounted. In this way, a NaI (Tl) detector responds to gamma rays. All the samples were kept one by one in a secure γ- ray chamber for roughly three hours in order to obtain results without errors. The ^{226}Ra, ^{232}Th, and ^{40}K concentrations in the given samples were estimated with the help of a NaI (Tl) γ Radiation Detector with dimensions 63 mm × 63 mm with an analyser having multi-channels. The experimental set-up is shown in Fig. 2. To calculate the ^{226}Ra, ^{232}Th, and ^{40}K activity, the 1764 keV γ line of ^{214} Bi, the 2610 keVγ line of ^{208}Tl, and the 1461 keV photo maximum were used, respectively. The SPTR-ATC programme was used to perform this spectral analysis (AT-1315). A reference standard source of material was used to calibrate the gamma spectrometer's energy and efficiency. By calculating the detector efficiency for ^{40}K, ^{238}U, and ^{232}Th, a calibration efficiency curve was acquired for NaI (Tl) detector. The samples' activity concentration was calculated from the total area under the photo peak using the following equation[9].

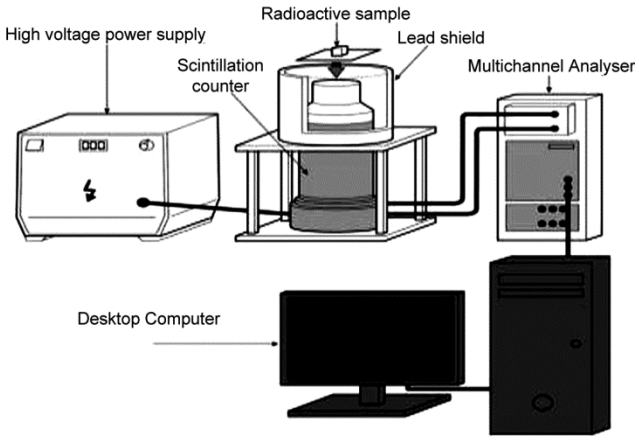

Fig. 2 — Schematic experimental arrangement showing NaI (Tl) Detector.

$$A_c = C_n / P_\gamma M \varepsilon \quad \ldots (3)$$

In which C_n is the total count rate under the commensurate maximum, A_c is the activity concentration of the radionuclide, P_γ is the modulus of transition probability of the specific γ-ray. Similarly, M- mass of the sample in kg, and ε is the detector's efficiency for particular γ-ray energy.

3.4 Estimation of radium equivalent activity

The concentration of radionuclides ^{226}Ra, ^{232}Th and ^{40}K is measured according to the Radium Equivalent Activity R_{aeq} in Bqkg^{-1} because of their non-uniform distribution in soil. It is assumed that the dose rates produced by "370 Bqkg^{-1} of ^{226}Ra, 259 Bqkg^{-1} of ^{232}Th, and 4810 Bqkg^{-1} of ^{40}K" are equivalent. The following relation is used to compute the equivalent activity of radium.

$$R_{eq} = A_{Ra} + 1.43A_{Th} + 0.07A_k \quad \ldots (4)$$

Where in A_{Ra}, A_{Th} and A_k are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1} respectively[10].

3.5 Absorbed dose rate

The concentration values of ^{226}Ra, ^{232}Th and ^{40}K in soil are used to estimate the absorbed dose rates for outdoor air from terrestrial γ-rays at 1m above the ground, with the assumption that other radionuclides like Cs-137, Sr-90, and the U-235 decay series can be disregarded because they have a little or no contribution to the overall dose received from the environment[11]. The formula

$$D = 0.461A_{Ra} + 0.623A_{Th} + 0.041A_k \quad \ldots (5)$$

Provides the factors of conversion which are used to estimate absorbed dose rates.

Table 1 — Radon activity and exhalation rates in a soil sample collected in the vicinage of Kolaghat Thermal Power Plant

Sample	Radon activity (Bqm^{-3})	Surface Exhalation rate E_A (mBqm^{-2}h^{-1})	Mass Exhalation rate E_M (mBqkg^{-1}h^{-1})
K-1	91.0 ± 8.5	32.7 ± 3.1	1.2 ± 0.1
K-2	48.8 ± 6.3	17.5 ± 2.2	0.6 ± 0.1
K-3	69.8 ± 7.5	25.1 ± 2.7	0.9 ± 0.1
K-4	67.5 ± 2.7	24.2 ± 2.6	0.9 ± 0.1
K-5	47.9 ± 6.2	17.3 ± 2.2	0.6 ± 0.1
K-6	66.6 ± 7.3	24.0 ± 2.6	0.9 ± 0.1
K-7	112.9 ± 9.5	40.7 ± 3.4	1.5 ± 0.1
K-8	91.0 ± 8.5	32.7 ± 3.1	1.2 ± 0.1
K-9	144.7 ± 10.8	52.1 ± 3.9	2.0 ± 0.2
K-10	157.6 ± 11.3	56.8 ± 4.1	2.1 ± 0.2
K-11	84.6 ± 8.3	30.4 ± 3.0	1.2 ± 0.1
Minimum	47.9 ± 6.2	17.3 ± 2.2	0.6 ± 0.1
Maximum	157.6 ± 11.3	56.8 ± 4.1	2.1 ± 0.2
Average	89.3 ± 7.9	32.1 ± 3.0	1.2 ± 0.1
Standard deviation	34.42	12.4	0.5

All of the daughters of ^{226}Ra, ^{232}Th and ^{40}K are thought to be in radioactivity equilibrium with their ancestral nuclei in the conversions mentioned above.

3.6 Effective dose rate (E)

The below-mentioned formula was implemented to compute the "effective dose rate (E)" in units of mSvy^{-1}

Indoor effective dose:

$$E_{in}(mSvy^{-1}) = D(nGyh^{-1}) \times 8760h \times 0.8 \times 0.7SvGy^{-1} \times 10^{-6} \quad \ldots (6)$$

Outdoor effective dose:

$$E_{out}(mSvy^{-1}) = D(nGyh^{-1}) \times 8760h \times 0.2 \times 0.7SvGy^{-1} \times 10^{-6} \quad \ldots (7)$$

3.7 External hazard index

The widely used hazard index is the external hazard index that reflects exposure to the outer end. The term "H_{ex}" is defined as follows[12].

$$H_{ex} = \frac{A_{ra}}{370} + \frac{A_{th}}{259} + \frac{A_k}{4810} \quad \ldots (8)$$

The respiratory system is also at risk from "radon" and its short-lived daughter nucleus, in addition to the external hazard index. The internal hazard index (H_{in}), which is determined by the following equation[13], measures the exposure to radon and decay products of radon in an indoor environment.

$$H_{in} = \frac{A_{ra}}{185} + \frac{A_{th}}{259} + \frac{A_k}{4810} \quad \ldots (9)$$

4 Result and Discussion

Table 1 shows the computed values for activity and exhalation rates due to radon in given samples of soil

collected from 11 various places in the vicinage of the "Kolaghat Thermal Power plant". The radon activity varies from 47.9 ± 6.2 to157.6 ± 11.3 Bqm^{-3} with an expectation value of 89.3 ± 7.9 Bqm^{-3}. Mass exhalation ranges from 0.6 ± 0.1 to 2.1 ± 0.2 $mBqkg^{-1}h$-1 averages out to1.2 ± 0.1 $mBqkg^{-1}h^{-1}$. Surface exhalation varies from 17.3 ± 2.2 to 56.8 ± 4.1 $mBqm^{-2}h^{-1}$ with an average of 32.1 ± 3.0 $mBqm^{-2}h^{-1}$.

The radon exhalation rates range considerably from one place to another. This may be because fly ash deposition on soil is different for different locations, and this may vary with distance from the power station. The "correlation" between uranium radioactivity concentration and rate of exhalations was found to be positive, as shown in Fig. 3. The radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K naturally occurring nuclides in soil and their mean values are shown in Table 2. The range of ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations ranges from 23.70 ± 3.41 to 33.90 ± 4.33 $Bqkg^{-1}$, 6.67 ± 2.01 to21.60 ± 2.11 $Bqkg^{-1}$ and 461.01 ± 66.16 to 610.25 ± 80.87 $Bqkg^{-1}$ with average of 29.26 ± 3.50, 16.54 ± 2.03 and 517.53 ± 71.61 $Bqkg^{-1}$ respectively. The activity concentration of radium, thorium, and potassium for given samples may also vary a little as the sodium iodide detector is sensitive to temperature. The spectrum may slightly shift on the x-axis due to changes in operating temperature caused by environmental temperature variations. For radio nuclei ^{226}Ra, ^{232}Th and ^{40}K, the weighted average concentrations throughout the world's population are 33, 45, and 420 Bqkg-1, respectively[15, 16]. The values calculated in this study for ^{226}Ra and ^{232}Th are found to be considerably lower than the recommended level. In contrast, the values for ^{40}K are found to be slightly higher than the recommended values. This may be because this area's soil contains more clay, and it is well known that in addition to solid waste, clay soil contains more exchangeable potassium due to higher cation exchange capability and organic materials. The second reason may be that potassium was released during the adsorption mechanism from the silicon wafer's surface and edges, which may have contributed to the increased Potassium contribution in the soil. These values were used to determine significant quantities associated with human health, such as internal and external effective dose indices and radiation risk indices, which are presented in Table 3. Radium equivalent activity ranges from 76.78 to 102.1 $Bqkg^{-1}$, Annual effective dose for internal and outdoor populations is found to vary from 0.19 to 0.25 and 0.048 to 0.063$mSvy^{-1}$respectively. The absorbed dose rate ranges from 39.30 to 51.61$nGyh^{-1}$. H_{ex} and H_{in} fluctuate from 0.21 to 0.28 and 0.29 to 0.36 with average values of 0.24 and 0.32, respectively. Radon effective doses in this sample were also calculated, which are found to vary from 2.04 to 6.70 μSvy^{-1} with a mean value of 3.79 μSvy^{-1}. Fig. 4 displays the plot variation of "equivalent activity of radium, annual effective dose and absorbed dose rate" for different soil samples. All the measurements present in this study are found to be well below their recommended levels.

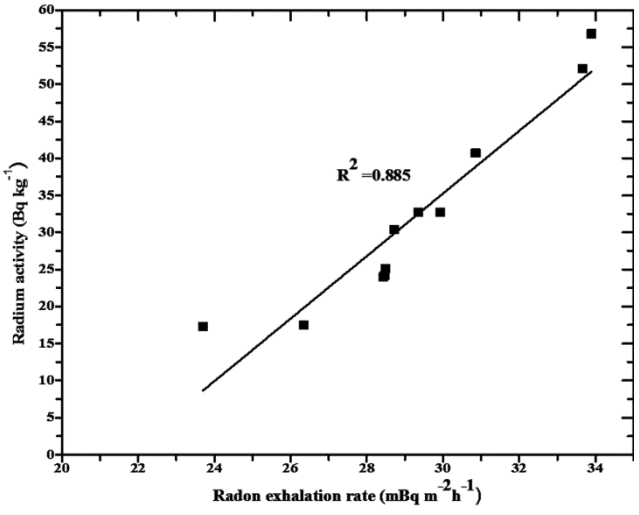

Fig. 3 — Correlation Curve between Activity of radium and Radon exhalation rate.

Table 2 — Ra, Th and K in soil of the surrounding areas of "Kolaghat Thermal Power Plant"

Sample	Activity concentration ($Bqkg^{-1}$)		
	Ra-226	Th-232	K-40
K-1	29.35 ± 3.90	19.41 ± 2.06	521.078 ±72
K-2	26.35 ± 3.69	20.81 ± 2.08	578.42 ± 77.38
K-3	28.50 ± 3.88	21.60 ± 2.11	610.25 ± 80.87
K-4	28.48 ± 3.80	21.14 ± 2.02	509.03 ± 70.44
K-5	23.70 ± 3.41	18.56 ± 1.96	497.82 ± 69.11
K-6	28.43 ± 3.69	21.28 ± 2.02	484.82 ± 68.15
K-7	30.86 ± 4.02	16.46 ± 2.03	481.82 ± 68.15
K-8	29.93 ± 3.99	13.6 ± 2.10	562.15 ± 76.26
K-9	33.66 ± 4.11	6.67± 2.01	479.77 ± 68.41
K-10	33.90 ± 4.33	10.91 ± 2.06	506.74 ± 70.85
K-11	28.72 ± 3.80	11.50 ± 1.97	461.01 ± 66.16
Mean	29.26 ± 3.50	16.54 ± 2.03	517.53 ± 71.61
Standard	2.78	4.8	44.6
deviation	23.70 ± 3.41	6.67 ± 2.01	461.01 ± 66.16
Minimum	33.90 ± 4.33	21.60 ± 2.11	610.25 ± 80.87
Maximum			

Table 3 — Risk factors related to human health

Sample	Radium equivalent activity Ra_{eq} ($Bqkg^{-1}$)	Absorbed dose rate D_{ab} ($nGyh^{-1}$)	Annual effective dose E_{in} ($mSvy^{-1}$)	Annual effective dose E_{out}(mSy^{-1})	Hazard index External H_{ex}	Hazard index internal H_{ex}	Representative level index I_y	Indoor inhalation exposure (radon) effective dose (μSvy^{-1})
K-1	99.26	46.98	0.23	0.057	0.25	0.34	0.73	3.86
K-2	96.60	48.82	0.24	0.059	0.27	0.34	0.76	2.06
K-3	102.1	51.61	0.25	0.063	0.28	0.36	0.81	2.96
K-4	94.34	47.16	0.23	0.057	0.26	0.34	0.74	2.85
K-5	85.08	42.90	0.21	0.052	0.23	0.30	0.67	2.04
K-6	92.80	46.24	0.23	0.056	0.25	0.33	0.72	2.83
K-7	88.12	44.23	0.22	0.054	0.24	0.33	0.69	4.79
K-8	88.72	45.31	0.22	0.055	0.25	0.33	0.71	3.86
K-9	76.78	39.30	0.19	0.048	0.21	0.30	0.61	6.14
K-10	84.97	43.20	0.21	0.052	0.23	0.33	0.67	6.70
K-11	77.44	42.10	0.21	0.051	0.21	0.29	0.61	3.58
Average	89.92	45.21	0.22	0.054	0.24	0.32	0.70	3.79
Standard	7.9	3.2	0.01	.003	0.02	0.02	0.05	1.46
Deviation	76.78	39.30	0.19	0.048	0.21	0.29	0.61	2.04
Minimum	102.1	51.67	0.25	0.063	0.28	0.36	0.81	6.70
Maximum								

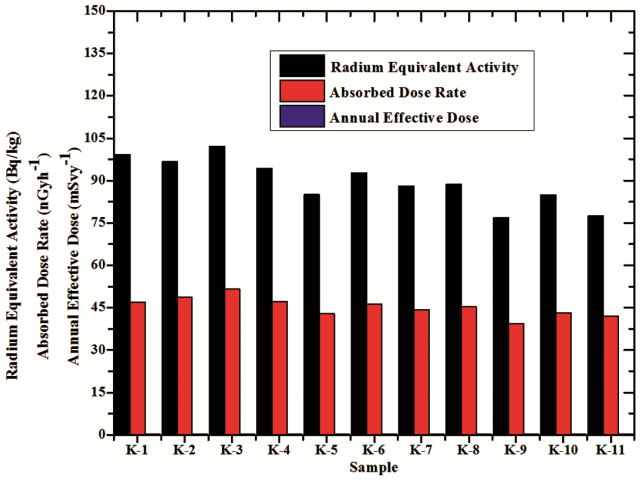

Fig. 4 — Bar diagram showing equivalent activity, annual effective dose, absorbed dose rate and in soil.

5 Conclusions

Utilising sodium iodide (thallium doped) gamma-ray spectrometry, the radioactivity concentrations of primaeval radionuclides were determined by preparing soil samples taken from various places from the vicinage of Kolaghat Thermal Power Plant. It was discovered that the positive correlation between uranium activity concentration and exhalation rate due to radon clearly indicates that the soil poses some radiological risk due to the deposition of fly ash in the soil. Except this, it has also been observed that the data reported in this paper is less than the average global value and within the usual level of radiation. Similarly, the effective dose in the soil of this region is within acceptable ranges, except for the potassium concentration, which is greater than the permitted levels. This data can be used as a baseline when estimating population exposure in this area. This work is regarded as unique and preliminary for this area and can be used moving forward for research in this area.

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