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Review article

Measurement of natural radioactivity in several sandy-loamy soil samples from Sijua, Dhanbad, India

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ABSTRACT

The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected from Sijua Dhanbad, India were measured by using a gamma-ray spectrometer with a NaI(Tl) detector. The average activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K was found as 60.3, 64.5 and 481.0 Bq. kg^{-1}, respectively. Average radium equivalent activity, absorbed dose rate, outdoor dose, external hazard index and internal hazard index for the area under study is determined as 189.5 Bq. kg^{-1}, 87.2 nGy h^{-1}, 0.4, 0.5 and 0.6 mSv. y^{-1}, respectively. The annual effective dose to the general public is found 0.4 mSv. y^{-1}. This value lies well below the limit of 1 mSv. y^{-1}. Measured values have found safe for the environment and public health of the study area.

1. Introduction

Natural radiation contributes to a major part of total radiation exposure to humans (Hendry et al., 2009; Agar et al., 2015). The carcinogenic effects due to the prolonged inhalation of radon progeny have been well established by several epidemiological studies (Baradaran et al., 2014). It is assumed that the gamma-ray exposure in the indoor environment is due to radiation emitted decay products containing ^{226}Ra, ^{232}Th, and ^{40}K (Nguelem et al., 2016). Radioactive materials with the characteristic of ionizing radiation are present in the vicinity of nature (Ahmed et al., 2019; Korkmaz et al., 2017). At every minute of life, humans are exposed to natural radiation. Uranium (^{238}U) content in the available soil has been found (34.58 Bq. kg^{-1}) but varies widely in different types of samples (Dhawal et al., 2014). Uranium being the parent element of the decay series in which radon as a member, plays an important role in radiation point of view (Buccianti et al., 2009).

Breathing in thorium in the workplace may increase the chances of development of lung diseases. Thorium is radioactive and can be stored in bones (Findeiß and Schäffer, 2017). Because of these facts, it has the ability to cause bone cancer many years after the exposure has taken place (Keith and Wohlers, 2015). Radon is a noble gas, produced by the decay of uranium. It is significant for the resolve of health risks for the population when used for dwelling construction, as most of the residents spend 80% of their time indoors (Stoulos et al., 2003).

Jharkhand is rich in uranium and coal (Giri et al., 2011). The extraction and use of coal cause many premature deaths and many illnesses (Report on Lignite coal, 2018). Coal damages the environment. These include fly ash, bottom ash, and flue-gas desulfurization sludge, that contain mercury, uranium, thorium, arsenic, and other heavy metals (Report on Toxic air, 2012). At present, there are 112 mines running at the district. As of March 2012, India only possesses two functional uranium mines, including this Jaduguda Mine. A new mine, Tummalapalle uranium mine. These radiations pose the greatest threat to human health, as they harm living cells, often leading to genetic mutation, cancer, and slow death. Environmental Hazards that come from the coal fires have poisonous gases that cause lung and skin diseases. The presence of mineral matter in coal may result in a number of environmental and human health problems related to its mining. During coal mining activities, large quantities of coal dust, ashes, and heavy metals are released into the environment, forming a complex mixture (Mejía et al., 2016). Briefly, air pollution occurs due to blasting and drilling operations, wind erosion from various dumps, and burning of coal fires. Once inside the organism, this combination can interact with cellular mechanisms related to the production of reactive oxygen species (ROS) and can cause damage in important macromolecules such as DNA, and lipids. Several

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studies have described the exposure to coal and coal fly ash particles; resulting in diseases widely described as cancer.

Concerning 20% of the natural radiation, a dosage is due to outdoor radiation from terrestrial radioactivity (Al-Jundi et al., 2003). The terrestrial constituent of the natural environment is dependent on the compositions of soil and some building materials, which characteristically enclose natural radionuclides (Agar et al., 2014). The soil is the main environmental material used for building raw materials (Ozmen et al., 2014a,b; Asokan et al., 2007; Mahur et al., 2008). The reported rate of increasing radiation concern in patients obtaining certain radiation treatment for lung cancer is 5%–36% (Davis et al., 2015). The study shows that 68.33% of deaths of people were happening before

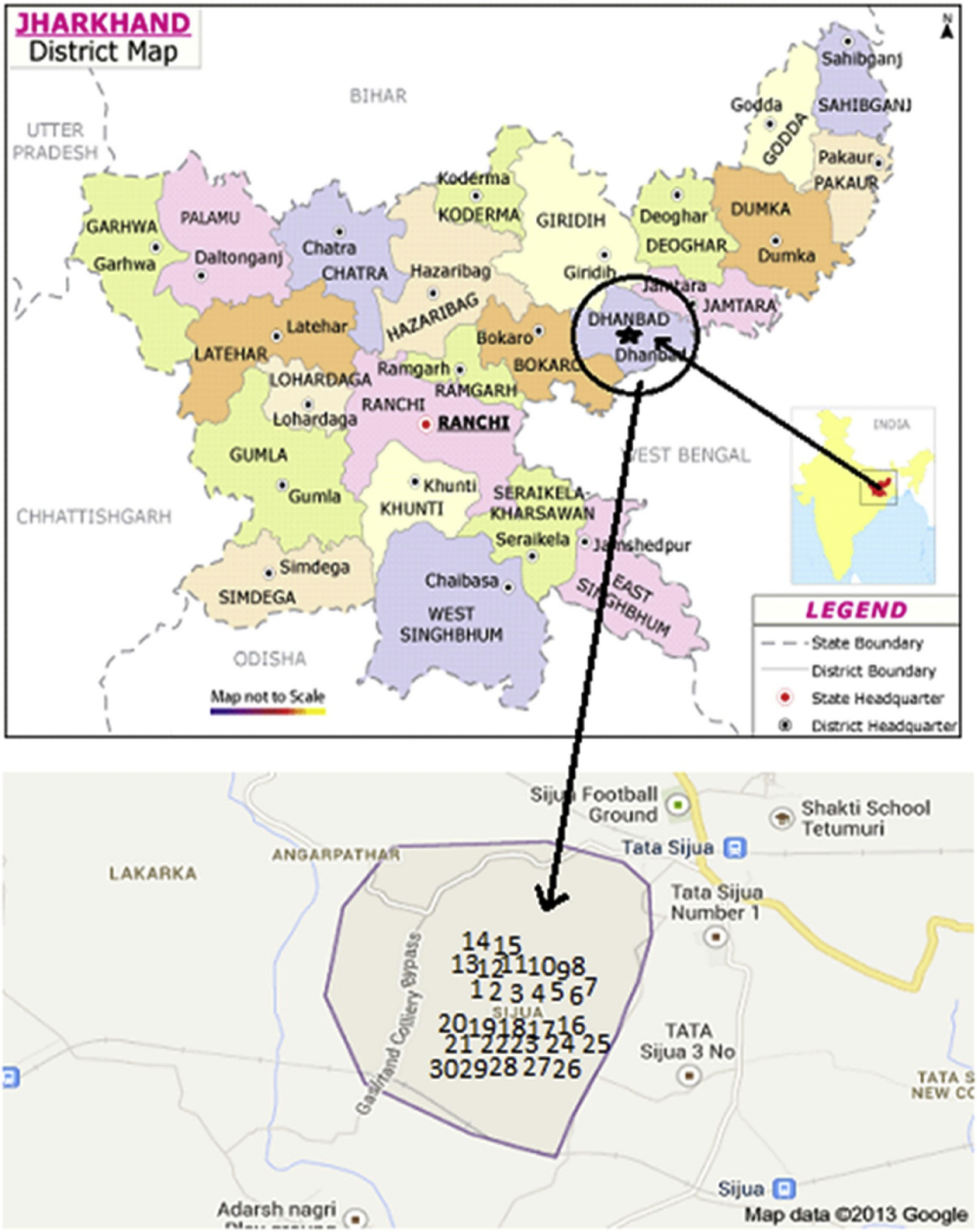

Figure 1. Numbers showing sampling locations.

attaining 62 years of age, which is living in the environs of uranium mining operational region (Dandona, 2019). In order to assess the radiation hazard of measured natural ^{226}Ra, ^{232}Th, ^{40}K activity concentrations, and radiological parameters are calculated.

2. Material and method

2.1. Geology of the area

Dhanbad district is located in a mid-eastern part of the Jharkhand state (Figure 1). The district has a total area of 2089 sq. km. having North latitude (23°26′ - 24°01′) and East longitude (86°10′ - 86°48′). Soils of the district are common in the residual type. High temperature and high rainfall have led to the creation of a lateritic type of soils from rocks of Archean metamorphic complex exposed in the greater part of the district and also from the lower Gondwana rocks in the west-central and east-central parts. Texturally soils of the district have been classified into four classes namely stony and gravelly soils, sandy soils, loamy soils, clayey soils.

Dhanbad is the largest city by population and second-largest urban agglomeration in Jharkhand after Jamshedpur. Dhanbad is famous for its coal mines and industrial establishments. There are a number of coal washeries present there. The distance between Dhanbad and Jaduguda is 166 km. The precambrian are the oldest formation of the region and forms the basement for the overlying Gondwanas. These primarily comprise of quartzite, mica-schist, granite-gneiss, migmatite, amphibolite and metadolerite, calc-gneiss and Augen-gneiss are also present in the region. Granite gneiss is the most common rock found in the district. It is a light-colored banded rock and consists of holocrystalline mineral assemblages of quartz and feldspar with accessory minerals such as biotite and hornblende. Stone is safe and suitable for road construction and building construction.

2.2. Sample preparation

Soil samples are collected from Sijua Dhanbad of Jharkhand (India) using agrab sampling method. Dhanbad to Sijua distance is 17.3 km. These samples were collected in a new and transparent plastic bag from the soil surface (depth, 0.30 m). After removing stones, samples were dried in an oven for the duration (hrs., 20–21) and temperature (130–150 °C), in order to remove moisture. After cooling (time, 1hr.), soil samples were crushed to powder and made homogeneous (mesh sieve, 150 μm). A sieved sample was placed in the bottom of the calibrated plastic cans and left to attain a secular equilibrium between ^{226}Ra, ^{232}Th, and their daughter products for a period of 4weeks before gamma spectrometric analysis (Jibiri et al., 2011). ^{226}Ra, ^{232}Th, and ^{40}K were measured in soil samples using a low background multichannel gamma-ray spectrometer system at National Geophysical Research Institute, Hyderabad. The sealed sample was placed in the protection unit of gamma-ray spectrometry (duration, 3 h) (Joshua et al., 2009).

2.3. Details of low background multichannel gamma-ray spectrometer system

The set-up comprises a 5 × 6 inch NaI (Tl) crystal coupled to a 5-inch diameter photomultiplier tube housed in a 7-inch thick lead shield (Figure 2). A 256-channel data set covering up to 3 MeV is obtained through a PC-based multichannel analyzing card (on an IBM personal computer) that provides a stabilized spectrum and also offers spectrum-analyzing facilities (Sukanta and Rao, 2003).

Each sample weighed about 0.5 kg and the counting time was varied between 10,000 and 25,000 s depending upon the activity level of the sample. Background intensities were obtained with an empty Marinelli beaker for the same time under the same conditions before and after the measurement of the samples. Then, the average of the background counts was subtracted from the sample spectrums. Gamma-ray spectra for uranium give several peaks at different energy levels, e.g., at 295, 352, 609, 780, 1120, 1390, 1760, 2200, 2450 KeV etc. The peak Bi-214 is considered due to the following reasons. (1) It is in high energy level, (2) it gives more counts and (3) it does not overlap with K (1460 KeV peak) and Th (2614 KeV peak). Similarly, gamma -ray spectra for Th give peaks at 236, 583, 920, 1620, 2130, 2614 KeV etc. and Tl-208 is considered for the same reason. The counts collected from the above peaks (K-40, Bi-214, and Tl-208) in gamma-ray spectrum are called potassium (K), equivalent uranium (eU) and equivalent thorium (eTh) respectively. Equivalent uranium means that the amount of uranium isotopes that were actually detected were adjusted to account for the other uranium isotopes (i.e., all of the uranium present is included). In this calculation main assumption is that radioactive elements and their decay products are in secular equilibrium. Calibrating standards were those prepared from the standards from the Atomic Energy Commission, New Brunswick. Uranium (in ppm), thorium (in ppm) and potassium (in %) can be computed in each sample.

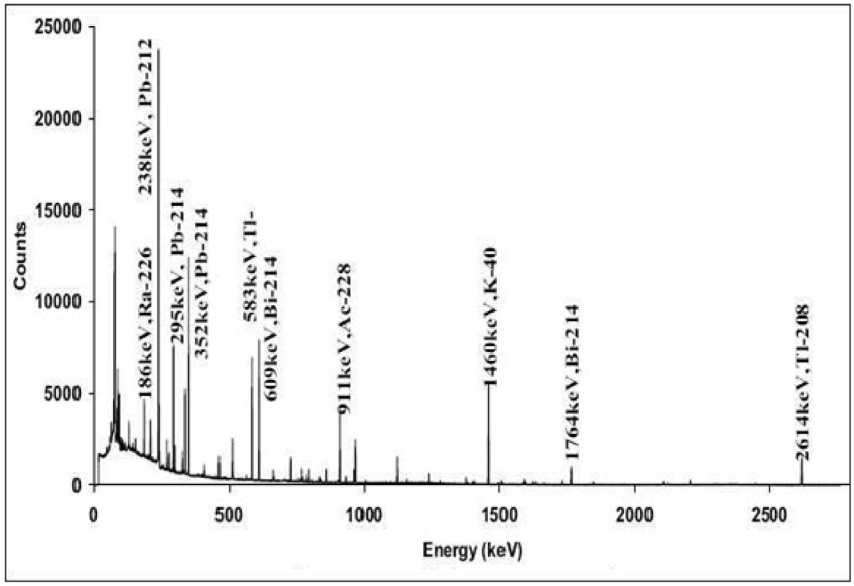

Figure 2. Gamma ray plot of soil sample.

Table 1. The estimated values of ^{226}Ra, ^{232}Th, ^{40}K, Radium equivalent activity and absorbed dose rate.

Sample Number	Radium (Bq. kg^{-1})	Thorium (Bq. kg^{-1})	Potassium (Bq. kg^{-1})	Radium equivalent activity (Bq. kg^{-1})	Absorbed dose rate ($^{(}$nGy h$^{-1)}$
1	44.50	66.99	500.8	178.81	82.03
2	45.70	59.28	594.7	176.26	81.90
3	55.40	64.00	788.3	207.61	97.36
4	99.70	95.20	402.1	265.80	120.50
5	205.60	136.10	466.8	436.20	196.80
6	47.60	58.20	549.2	173.11	105.82
7	58.50	84.02	624.6	226.74	104.00
8	47.30	79.20	473.6	197.02	69.71
9	116.40	56.40	343.5	223.50	102.27
10	24.30	59.20	179.5	122.80	54.52
11	32.40	65.30	365.5	153.92	69.80
12	35.70	36.06	295.4	110.01	50.70
13	70.04	45.51	611.9	182.24	85.55
14	43.00	56.40	296.3	146.50	66.40
15	63.20	49.50	356.2	161.41	74.06
16	78.30	39.80	478.5	172.06	80.31
17	134.90	57.40	795.9	278.30	130.42
18	27.20	55.60	532.1	147.70	68.50
19	92.70	105.80	437.8	277.70	125.12
20	15.60	68.20	314.5	137.34	61.60
21	78.50	59.70	65.8	168.94	75.10
22	42.80	65.80	345.8	163.52	74.04
23	43.10	42.70	573.8	148.34	69.80
24	43.23	60.90	594.7	176.10	81.73
25	44.46	60.90	532.1	172.52	79.70
26	46.93	58.46	594.7	176.32	82.00
27	39.52	61.31	532.1	168.20	77.64
28	46.93	67.80	563.4	187.30	86.30
29	41.99	60.10	626.0	176.12	82.00
30	43.23	59.30	594.7	173.80	81.00
Minimum	15.60	36.10	65.8	110.01	50.70
Maximum	205.60	136.10	795.9	436.20	196.80
Mean	60.30	64.50	481.0	189.53	87.21
S. D.	38.34	19.81	162.6	61.50	28.20

2.4. Radium equivalent activity

It is understood that one and all decay products of ^{226}Ra and ^{232}Th are in radioactive equilibrium with their forerunners. The Ra_{eq} is calculated according to the following formula (Raghu et al., 2017).

$$Ra_{eq} = 0.077C_K + 1.43C_{Th} + C_{Ra} \quad (1)$$

where C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1}, respectively. Eq. (1) is based on the assessment that ^{226}Ra (370 Bq. kg^{-1}), ^{232}Th (259 Bq. kg^{-1}) or ^{40}K (4810 Bq. kg^{-1}) produce the same gamma ray dose rate (Ibrahim, 1999).

2.5. Air absorbed gamma-radiation dose rate

The absorbed dose rates (nGy h^{-1}) in outdoor air from global gamma radiation at 1 m above the ground were analyzed by the next equation (Ozmen et al., 2014a,b; Curtin et al., 2008).

$$D_{ab} = 0.042C_K + 0.604C_{Th} + 0.462\ C_{Ra} \quad (2)$$

2.6. Annual average effective dose rates

The annual effective dose expected to be received by the general public due to radioactivity in the soil was calculated using a conversion factor of 0.7 Sv Gy^{-1} (Jibiri et al., 2007), to convert the absorbed dose rate to the effective dose equivalent with indoor and outdoor occupancy factor of 0.8 and 0.2, respectively (Tzortzis et al., 2003). The annual effective doses are determined as follows:

$$\text{Indoor effective dose} = D_{ab} \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \quad (3)$$

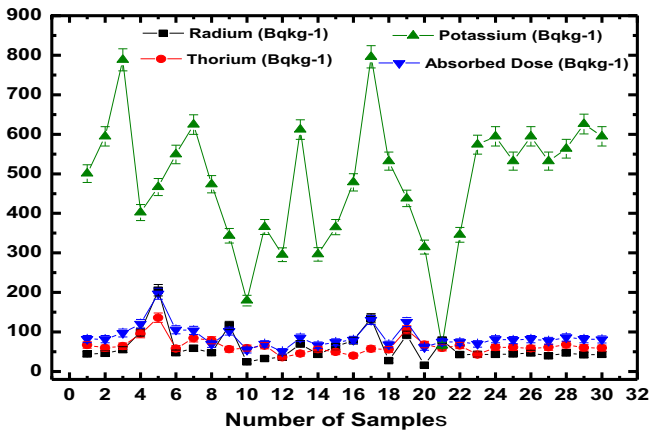

Figure 3. Absorbed dose rates due to the natural radioactivity in different samples.

Table 2. The indoor and outdoor annual effective doses (mSv. y^{-1}), external hazard index (H_{ex}), internal hazard index (H_{in}), gamma index (I_γ) and alpha index (I_α) in soil samples.

Sample Number	Annual effective doses		Hazard index		Gamma index	Alpha index
	Indoor	Outdoor	External	Internal		
1	0.40	0.10	0.48	0.60	0.65	0.22
2	0.40	0.10	0.48	0.60	0.64	0.23
3	0.50	0.12	0.56	0.71	0.77	0.28
4	0.60	0.15	0.72	0.99	0.94	0.50
5	0.98	0.24	1.18	0.67	1.37	1.03
6	0.86	0.13	0.47	0.60	0.63	0.24
7	0.52	0.13	0.61	0.77	0.82	0.29
8	0.35	0.09	0.53	0.66	0.71	0.24
9	0.51	0.13	0.60	0.92	0.78	0.58
10	0.27	0.07	0.33	0.40	0.44	0.12
11	0.35	0.09	0.42	0.50	0.45	0.16
12	0.25	0.06	0.30	0.39	0.40	0.18
13	0.43	0.10	0.49	0.68	0.67	0.35
14	0.33	0.09	0.40	0.51	0.52	0.22
15	0.37	0.09	0.43	0.61	0.58	0.32
16	0.40	0.10	0.46	0.68	0.62	0.39
17	0.65	0.16	0.75	1.12	1.00	0.67
18	0.34	0.07	0.39	0.47	0.55	0.14
19	0.63	0.15	0.75	1.00	0.99	0.46
20	0.31	0.08	0.37	0.41	0.50	0.08
21	0.38	0.09	0.67	0.67	0.58	0.39
22	0.37	0.09	0.44	0.56	0.55	0.21
23	0.35	0.09	0.40	0.52	0.55	0.22
24	0.40	0.10	0.48	0.59	0.64	0.22
25	0.39	0.09	0.47	0.59	0.63	0.22
26	0.40	0.10	0.48	0.60	0.65	0.23
27	0.38	0.10	0.46	0.56	0.62	0.20
28	0.42	0.11	0.51	0.63	0.69	0.23
29	0.40	0.10	0.48	0.59	0.65	0.21
30	0.39	0.09	0.47	0.58	0.64	0.22
Minimum	0.25	0.06	0.30	0.39	0.40	0.08
Maximum	0.98	0.24	1.18	1.12	1.37	1.03
Mean	0.44	0.37	0.52	0.64	0.67	0.30
S. D.	0.16	1.43	0.17	0.17	0.20	0.19

$$\text{Outdoor effective dose} = D_{ab} \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (4)$$

2.7. External and internal hazard index

The internal and external hazard indexes are calculated by the following expressions (Rafique et al., 2013):

$$H_{in} = \frac{C_K}{4810} + \frac{C_{Th}}{259} + \frac{C_{Ra}}{185} \quad (5)$$

$$H_{ex} = \frac{C_K}{4810} + \frac{C_{Th}}{259} + \frac{C_{Ra}}{370} \quad (6)$$

where C_K, C_{Th} and C_{Ra}, are the activities of ^{40}K, ^{232}Th and ^{226}Ra and inBq.kg^{-1}, respectively.

2.8. Gamma index

The gamma emission index (I_γ) is one of the health indices dealing with the assessment of the excess external and indoor gamma radiation from building materials (EC Report, 1999).

$$I_\gamma = \frac{C_K}{3000} + \frac{C_{Th}}{200} + \frac{C_{Ra}}{300} \quad (7)$$

A value of 0.5 or less for I_γ corresponds to a dose rate ($\geq$ 0.3 mSv. y^{-1}), while a value of 1 or less for (I_γ) corresponds to a dose rate of 1.0 Bq. kg^{-1} (Turhan et al., 2008).

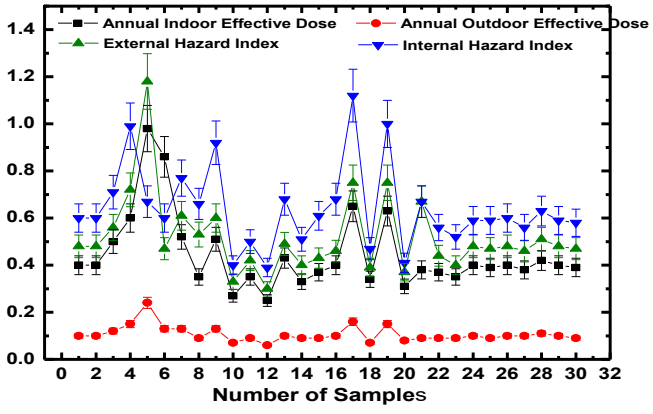

Figure 4. The comparison of external (H_{ex}) and internal (H_{in}) radiation hazard indices.

Table 3. Comparison of natural radioactivity with other studies worldwide.

Sample Number	Location	^{226}Ra (Bq. kg^{-1})	^{232}Th (Bq. kg^{-1})	^{40}K (Bq. kg^{-1})	References
1	Kalpakkam, South, India	22.63	92.79	434.08	(Sowmya et al., 2010)
2	Garhwal Himalaya, India	75.99	106.32	979.60	(Ramola et al., 2008)
3	Thanjavur (Tamil Nadu, India)	15.93	45.73	188.30	(Senthilkumar et al., 2010)
4	Punjab and Himachal Pradesh, India	56.74	87.42	143.04	(Singh et al., 2005)
5	Upper Siwaliks and Punjab, India	37.70	74.90	554.00	(Singh et al., 2008)
6	Bursa, Turkey	25.00	26.00	435.00	(Akkaya et al., 2012)
7	Territories of Mongolia	28.20	31.80	840.70	(Shagjjamba and Zuzaan, 2006)
8	Central Kutahya, Turkey	33.00	32.00	255.00	(Sahin and Cavas, 2008)
9	Russaifa region, Jordan	284.44	16.49	146.44	(Hamideen and Sharaf, 1993)
10	Assiut, Egypt	46.15	30.57	553.14	(Gamal et al., 2013)
11	Southern Egypt	12.16	6.30	432.84	(Sroor et al., 2001)
12	Ptolemais (Northern Greece)	42.00	36.00	496.00	(Psichoudaki and Papaefthymiou, 2008)
13	Coal-fired thermal power plant, China	40.30	59.60	751.20	(Lu et al., 2012)
14	Coal mining in Nigeria	49.97	57.17	89.82	(Balogun et al., 2003)
15	Southwestern region of Nigeria	54.50	91.10	286.50	(Ajayi, 2009)
16	UNSCEAR, 2000	35.00	30.00	400.00	(UNSCEAR, 2000)
17	Dhanbad city (Jharkhand)	44.00	61.70	570.40	Present study

2.9. Alpha index

The alpha index (I_α) has been suggested to assess the exposure level due to radon inhalation originate from building materials (Ravisankar et al., 2012). The internal index is defined as follows:

$$I_\alpha = \frac{C_{Ra}}{200} \quad (8)$$

The recommended exemption level and the recommended upper level for ^{226}Ra is 200 Bq.kg^{-1} (ICRP, 1993).

3. Results and discussion

As seen in Table 1, values of ^{226}Ra activity is found to vary from 15.60 to 205.6 Bq. kg^{-1} with a mean value of 60.29 Bq. kg^{-1} and a standard deviation of 38.34 whereas the values of ^{232}Th activity is found to vary from 36.06 to 136.1 Bq. kg^{-1} with a mean value of 64.50 Bq.kg^{-1}. The level of ^{232}Th is found at 64.50 Bq. kg^{-1}. It is higher than the world average value of 30 Bq. kg^{-1}. The activity values of ^{40}K have been found to vary from 65.8 to 795.87 Bq. kg^{-1} with a mean value of 481.0 Bq.kg^{-1}, which is indeed more than the worldwide average of 400 Bq. kg^{-1}. The activity of ^{40}K is found higher than the activity of ^{226}Ra and ^{232}Th in all soil samples. The value of Ra_{eq} in these soil samples are found to vary from 110.01 to 436.16 Bq. kg^{-1} with a mean value of 189.53 Bq. kg^{-1} and a standard deviation of 61.48. The radium equivalent activity in soil samples was found lower than 370 Bq. kg^{-1} (OECD, 1979). The absorbed dose rate varied from 50.68 to 196.80 nGy h^{-1} with a mean value of 87.21 nGy h^{-1} and a standard deviation of 28.17. The average absorbed dose rate values calculated for each sample are shown in Table 1. The absorbed dose rate estimated from the soil for the Indian sub-continent is about 69 nGy h^{-1} (Maharana et al., 2010). All values of the absorbed dose rate are higher than the world average value i.e., 55 nGy h^{-1} (Singh et al., 2005). The value of absorbed dose rate varies due to ^{226}Ra, ^{232}Th, and ^{40}K. Figure 3, indicates the mean value in order ^{40}K > ^{232}Th > ^{226}Ra. The graph shows both vertical and horizontal. Vertically, we connect to activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and absorbed dose. Horizontally, we connect with the sample number. We must realize that a relationship with concentration (vertical) directly affects our relationship with people (horizontal). Vertical and horizontal relationships are both significant and necessary.

All samples are collected from the city area except locations 5 and 17. Therefore potassium concentration is minimum in overall samples. Only two locations (No 5 and No 17) shows high values of concentration, this may be due to soil samples are collected near to the coal mines. Table 2 shows that the annual indoor effective dose rates in soil samples was found to vary from 0.25 to 0.98 mSv. y^{-1} with an average value of 0.44 mSv. y^{-1} and a standard deviation of 0.16, while the annual outdoor effective dose rate was found to vary from 0.06 to 0.24 mSv. y^{-1} with an average value of 0.37 mSv. y^{-1} and a standard deviation of 1.43 (Table 2). This average value of an outdoor annual effective dose is higher than the worldwide average value of 0.07 mSv. y^{-1}. The calculated values of the external hazard index varied from 0.30 to 1.18 with a mean value of 0.52 and a standard deviation of 0.17 whereas calculated values of internal hazard index varied from 0.39 to 1.12 with a mean value of 0.64 and a standard deviation of 0.17. As seen in Figure 4, values of external and internal hazard indices in the present study have been found less than unity, indicating that soil from this study area is safe for use in construction and does not pose any significant harmful effects to inhabitants.

A value of 0.5 or less for gamma index corresponds to a respectively in the sample effective dose equivalent rate of $\geq$ 0.3 mSv. yr^{-1}, while a value of 1 or less for gamma index corresponds to a dose rate of 1.0 mSv. yr^{-1}. However, the gamma index has found from 0.40 to 1.37 with a mean value of 0.67 and a standard deviation of 0.02. All the values of the gamma index were found below the limit of 1. Hence the value of the annual effective dose rate due to the soil sample is less than 1 mSv. yr^{-1} (Table 2). The alpha index has been found to vary from 0.08 to 1.03 with a mean value of 0.30 and a standard deviation of 0.19. As indicated in Table 2, the value of the alpha index was found less than the maximum permissible value of 1. Obtained results are comparable to the worldwide average concentration (Table 3).

4. Conclusion

Activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from the coal mines Jharkhand (the largest producer of coal among all Indian states) were assessed by using HPGe ãray spectrometry. The mean activity values of ^{226}Ra, ^{232}Th and ^{40}K have been found to be 60.30 Bq. kg^{-1}, 64.50 Bq.kg^{-1} and 481.0 Bq. kg^{-1}, respectively. A relatively high level of NORMs was found in location no 5 and 17 collected from the open cast mine that is located near to the colliery areas

(Sijua group of mines). ^{40}K found to be the highest followed by ^{226}Ra and then ^{232}Th. However, measured data for ^{226}Ra, ^{232}Th and ^{40}K were found to be higher than the world average values of 35 Bq. kg^{-1} for ^{226}Ra, 30 Bq. kg^{-1} for ^{232}Th and 400 Bq. kg^{-1} for ^{40}K because Jharkhand is one of the richest areas in the whole country, rich in minerals deposit and forests. The region has a huge reserve of coal, iron ore, mica, bauxite and limestones and considerable reserves of copper, chromite, asbestos, kyanite, tungsten, feldspar, quartz, china clay, manganese, dolomite, uranium, etc. Environmental hazards the smoke that comes from the coal fires have poisonous gases including oxides and dioxides of carbon, nitrogen, and sulphur; and particulate matter which causes lung and skin diseases. However, Average value of radium equivalent activity is 189.53 Bq.kg^{-1}, which is below the recommended value of 370 Bq. kg^{-1}. The mean value of air absorbed gamma radiation dose rate is 0.67 nGy h^{-1} which generates an annual effective radiation dose of 0.44 mSv. y^{-1}. This is much below the limit of 1 mSv. y^{-1} recommended by the ICRP for the general population. The internal and external radiation indices have been found below the limit of unity as well as the mean value of the gamma index is obtained below the limit of 1 mSv. y^{-1}. Also, the obtained values for the alpha index have found below the maximum permissible value. On the basis of these results, it is concluded that the soil of the study area does not pose any radiological hazard to the public and environment.

Declarations

Author contribution statement

M. Zubair: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; wrote the paper.

Shafiqullah: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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