Indian Journal of Pure & Applied Physics
Vol. 61, November 2023, pp. 945-954
DOI: 10.56042/ijpap.v61i11.3115

Natural Radionuclides in Surface Soil and Quantification of Associated Radiological Hazards in Fatehabad and Hisar districts, Haryana, India

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Received 26 June 2023; accepted 29 August 2023

Elevated levels of primordial radionuclides (^{238}U/ ^{232}Th- decay series and ^{40} K) are the foremost source of higher background radiations. Natural radioactive elements may prove precariously radioactive in some situations. So, it is essential to quantify the natural levels of radioactivity in the soil to figure out how much the population is exposed to, what the health risks are, and have a starting point for figuring out how radioactivity in the environment will change due to human activities. In this study natural radioactivity in the soil of different residential areas of Fatehabad and Hisar districts in Haryana, India has been quantified. HPGe gamma spectrometry has been used to quantify the activity of ^{226}Ra, ^{232}Th, and ^{40}K in the soil of the area under investigation. The respective activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K ranged 32 to 53 Bq kg^{-1}, 23 to 41 Bq kg$^{-1,}$ and 402 to 610 Bq kg^{-1}. The activity equivalent to radium only (Ra_{eq}), the air absorbed dose rate (AAD), the effective dose equivalent rate(AEDEC), the gonadal dose equivalent rate (AGDE), the external risk index, the internal risk index, the index for gamma level, cancer risk for an average lifetime, etc. were calculated and compared with the international standards. Each sample of soil had lesser radium equivalent activities than the permissible limit, *i.e.*, 370 Bq kg^{-1}primarily set by the Organisation for Economic Co-operation and Development (OECD), and the effective dose equivalent was below the safe limit of 1.0 mSv y^{-1}. Organ-specific dose values are pretty considerable but not in the danger zone. The Clark value refuses the probability of finding any uranium ore. This study indicates that the area being studied is a place with low background radiation exposure from radionuclides.

Keywords: Soil; Cancer risk; Natural radioactivity; Hazard index; HPGe detector; Radium equivalent activity

1 Introduction

Radioactivity's effects on human health have been a serious concern[1]. Natural radiation, like the sun's heat and light, are inherent in the environment. Natural background radiation exposure is 1.1 mSv annually. Cosmic rays (0.35 mSv), air background radiation (0.05 mSv), etc. may also contribute[2,3] to natural dose. When radionuclides bioaccumulate in the environment, their unique biogeochemical processes and high mobility threaten ecosystems and human health. Radioactive isotopes in the environment expose humans to external radiation, while lungs and digestive tracts absorb internal radiation[4]. Primordial radioactive elements, such as ^{40}K gamma rays and ^{238}U and ^{232}Th radioactive series in soil, water and rocks, can expose humans to ionizing radiation[5,6,7,8]. So, most radioactivity measurement studies focus on natural background radiation from primordial radionuclides since they account for about 80% of a person's annual radiation dose[9]. Natural background radiation accounts for 67.6% of a person's overall radiation exposure, less than many other sources (such as professional exposure, discharges from nuclear facilities, medical radiation fallout, etc.). High radioactive radiation levels been linked to volcanic and metamorphic rocks while sedimentary rocks have been linked to lower levels of radiation[10,11]. Exposure to natural and extra-terrestrial radiation varies in intensity and varies by region due to differences in geological and radiochemical characteristics[12,13].

In the last ten to twenty years, there has been an upsurge in the investigation of radioactivity in soils and parent rocks around the world (both on an individual and organizational level)[13,14,15]. Soil is an essential aspect of radioactive pollution because it transports radionuclides to biological systems[16]. Soil radioactivity is also used to analyze radiation hazards,

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nuclear safety, and exploration[17]. We can't say enough about how important it is to find out how much radioactivity is in the soil samples of a geological formation to figure out what effects radioactivity might have on the people who live there. This is especially true when we consider the number of people who live in such a formation as a community. This is because there are different kinds of geological formations on the solid earth that people depend on for their survival. This study assesses the radiological risks posed by naturally existing radioactivity in Hisar and Fatehabad districts, India. This examines the existence and activity levels of natural ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in surface soil in the area under the study. The absorbed dose rate, Ra_{eq} (radium equivalent), yearly effective absorbed amount, and gamma and alpha radiation hazard indices are computed to determine the radiological influence of these radionuclides on the inhabitants and the atmosphere.

2 Study area and its geological settings

Haryana is characterized by four distinct landscapes: the vast Yamuna-Ghaggar plain, the forested north-east through Shivalik Hills, a semi-arid sand plain to the southwest, and the mountainous Aravalli Range to the south. Hisar and Fatehabad, two western Haryana districts well-known for their industries, agriculture, and historical significance, have been chosen for the study of subsoil natural radioactivity. The decision to focus on the specific study region was motivated by the construction of a nuclear power plant in the area. By creating a comprehensive radioactivity map of the wider region, we aim to establish a baseline for future comparisons after the nuclear power plant's commissioning.

Additionally, we acknowledge the importance of addressing the time gap since previous studies were conducted. By comparing present findings with earlier studies, we can assess whether any natural change in radioactivity have occurred over time, separate from the influence of the power plant's operation. This comparative analysis provides valuable insights into the potential impact of the power plant on the area's radioactivity levels. The study area and sampling location have been presented in Fig. 1. It is spread between 28^{O}95'N to 29^{O}45'N and 75^{O}15'E to 76^{O}17'E, latitude, and longitude, respectively. The area under investigation is also a culturally significant portion of the Saraswati Valley civilization. The soils in the study region are sandy, sandy loam, and clay. The area under investigation is an alluvial plain in the Indo-Gangetic basin. The region's geography, as a whole, is a level plain with an average elevation of 215m that gently slopes from north to south and east to west[18]. Most of the locals make their living in the

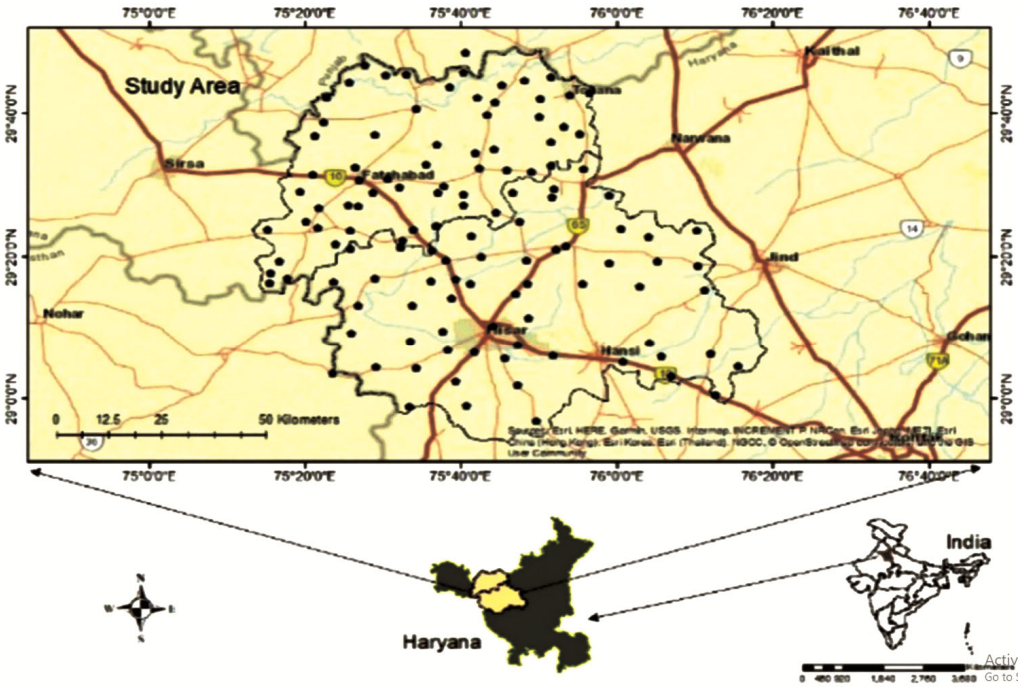

Fig. 1 — Study area map with different sampling locations. (*The map is only intended to be used as a visual aid and do not indicate any view on the legal positionof any country or territory or the delimitation frontiers or boundaries.)

agricultural and animal husbandry industries. The area is also acquainted with wind erosion.

3 Investigational steps

3.1 Field and laboratory preparation

120 topsoil samples (60 from each district) were taken at various times of the year from a variety of locations. A composite soil sample weighing around a thousand grams was collected and their exact GPS coordinates were recorded. Soil samples were screened to remove any large stones air and oven-dried at 110 °C for at least 72 h to remove all the moisture from the samples, ground to make them homogenous, then passed through a sieve, sealed in polyethylene air-tight containers, weighted, and stored for four weeks to allow the Radon and Thoron, and their descendant having small half-lives, to achieve the consistency with their parents.

3.2 Instrumentation and spectrum measurement

The Co-axial p-type Hyper Pure Germanium (HPGe) detector has been used in this investigation. The instrument's relative efficiency (with respect to a 3" X 3" NaI(Tl) scintillation detector and a point source of ^{60}Co positioned 25cm height from the detector) for 1.332 MeV peak is 50 per cent. Its full-width half maximum is 0.009 MeV for the photo peak 0.122 MeV emitted by ^{57}Co and 0.02 MeV for the photo peak 1.332 MeV emitted from ^{60}Co. The samples and the background were counted for 80,000 seconds.

At 1461 keV (10.7% abundance) a gamma emission was used to directly quantify the activity level of ^{40}K. The ^{226}Ra activity was calculated by the gamma energy 0.609 MeV (45% abundant) and 1.764 MeV (16% abundant) photo peaks of its daughter ^{214}Bi. Whereas the ^{232}Th activity was estimated using 0.911MeV (branching ratio, 27.8%) and 0.583 MeV (branching ratio, 86%) photo peaks emitted by ^{228}Ac and ^{208}Tl, respectively.

3.3 Instrument calibration

Both energy and efficiency calibrations are required for a gamma-ray detection system. The energy calibration, which translates channel counts into MeV of gamma-ray energy, and the efficiency calibration, which attempts to quantify this efficiency throughout the whole spectrum of measurable energies, are essential for accurate measurements. High-quality verified reference sources of density comparable to that of the samples were used to standardize the detection system's efficiency and energy. To ensure accurate measurements, authors conducted energy and efficiency calibration of the spectrometer using a standard mixed multi-nuclide source provided by BARC, Mumbai and ESL, Tarapur. The efficiency curve is given in Fig. 2. This source contained a combination of ^{40}K, ^{60}Co, ^{134}Cs, ^{137}Cs, and ^{133}Ba. Both the standards and samples were counted under uniform geometry for consistency. Also, the source used as a reference for calibration purposes was put in the same position as the samples. To calibrate for energy, the gain of the pre-amplifier was set to detect a wide range of gamma rays.

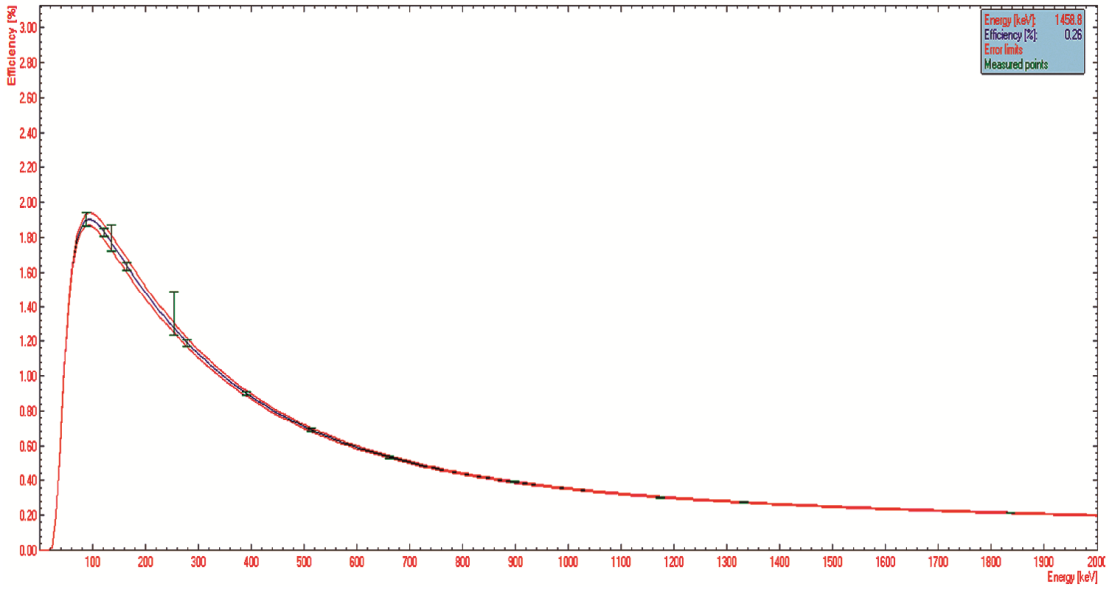

Fig. 2 — Efficiency curve of HPGe spectrometer

4 Estimation of soil radiological parameters

The radioactivity of primordial radionuclides has been represented by A_{Ra}, A_{Th}, and A_K while calculating various radiometric parameters in the present study. The gamma-ray spectrum counts obtained from the aforementioned peaks are known as potassium (K), uranium equivalent (eU), and thorium equivalent(eTh), respectively. Uranium equivalent indicates that the amount of observed uranium isotopes was modified to compensate for the various uranium isotopes. The fundamental premise of this computation is that radionuclides and thereby products are in equilibria.

4.1 Calculation of Activity (Bq kg^{-1})

Using the equation (1), the activity levels (A_i) of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides have been estimated.

$$Activity A_i(\text{Bq kg}^{-1}) = \frac{Net\ count\ of\ specific\ peak}{efficiency \times time \times mass} \quad \ldots(1)$$

4.2 Radium equivalent activity (Ra_{eq})

The radium equivalent is concerned with the external and internal gamma and alpha dose, respectively, emitted by radon and its offsprings. Ra_{eq} activity has been calculated using equation[20] (2):

$$Ra_{eq} = A_{Ra} + 1.43 \times A_{Th} + 0.077 \times A_K \quad \ldots(2)$$

This value in building soil should lie below 370Bq kg^{-1} for harmless use, which equates to a real dosage of 1 mSv y^{-1} for dwelling occupants[13].

4.3 External hazard index (H_{ext})

H_{ext} (Model I) was determined employing equation[13] (3)

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots(3)$$

Model II extended for a room having ventilation in the form of doors and windows and estimated with the help of equation[13] (4):

$$H_{ext} = \frac{A_{Ra}}{740} + \frac{A_{Th}}{518} + \frac{A_K}{9620} \leq 1 \quad \ldots(4)$$

Where all the three isotopic radioactivity factors in Eq. (4) are reduced by half that were used in Eq. (3). The inclusion of ventilation in model II will result in some type of airflow in the model room, reducing the exposure of people to radionuclides and all types of dosages.

4.4 Internal hazard index (H_{int})

Short-lived radionuclides release alpha particles that are harmful to the lungs if inhaled. These include ^{222}Rn, belonging to ^{226}Ra, and ^{220}Rn, belonging. ^{234}Th. The following equation[21] (5) was used to calculate the internal hazard index (H_{int})

$$H_{int} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots(5)$$

An index (H_{int}) below unity indicates that a given soil can be used without risk in the construction of residential structures.

4.5 External gamma level index ELI

This indicator also called the characteristic level index, was derived using equation[22] (6)

$$\text{ELI} = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 1 \quad \ldots(6)$$

4.6 Internal alpha level index ILI

The extra alpha contamination due to ^{222}Rn inhalation released from the soil is estimated utilizing the following equation:

$$\text{ILI} = \frac{A_{Ra}}{200} \leq 1 \quad \ldots(7)$$

The indoor radon levels cannot exceed 200 Bq m^{-3} due to the absence of Ra concentrations beyond 200 Bq kg^{-1}, the following statement holds true.

4.7 Activity utilization gamma index (AUI)

The activity concentrations of natural radioactivity in soil mostly affect the interior absorbed dose in enormous houses built of brick. The equation[24] (8) was used to find out this index:

$$\text{AUI} = 0.0809\frac{A_{Ra}}{50} + 0.4798\frac{A_{Th}}{50} + 0.4392\frac{A_K}{500} \leq 2 \quad \ldots(8)$$

4.8 Exposure rate (ER)

The ER was estimated using equation[23] (9) given below:

$$R\ (\mu Rh^{-1}) = 1.90\,A_{Ra} + 2.82\,A_{Th} + 0.179\,A_K \quad \ldots(9)$$

4.9 Relative Dose rate (DR) to exposure rate

The DR was determined using below given equation[23] (10):

$$DR(mrem\ y^{-1}) = 8.33 \times ER(\mu Rh^{-1}) \quad \ldots(10)$$

4.10 Air Absorbed Dose (D_{air})

The external absorbed dose of gamma radiation from the air at about one meter above the surface was quantified using equation[13] (11)

$$D_{air}(nGy\ h^{-1}) = 0.461 \times A_U + 0.623 \times A_{Th} + 0.0417 \times A_K \quad \ldots(11)$$

4.11 Annual effective dose equivalent (AEDE)

The AEDE was estimated using the below-given formulae[13]:

$$AEDE(Indoor)(\mu Sv\ y^{-1}) = D_{air}(nGy\ h^{-1}) \times 8760\ h \times 0.8\ \times\ 0.7\ SvG\ y^{-1} \times 10^{-3} \quad \ldots(12)$$

$$AEDE(Outdoor)(\mu Sv\ y^{-1}) = D_{air}(nGy\ h^{-1}) \times 8760\ h \times 0.2\ \times\ 0.7\ SvG\ y^{-1} \times 10^{-3} \quad \ldots(13)$$

4.12 Effective dose rate (D_{organ}) to definite tissues or body organs

The effective dose distributed to a definite body part may be quantified by means of the below-given equation[25] (14):

$$D_{organ}(\mu Sv\ y^{-1}) = AEDE \times f \quad \ldots(14)$$

where f is the factor used for the conversion of AEDE to definite organ dose for the Whole Body (0.68), Testes (0.82), Bone marrow (0.69), Ovaries (0.58) and Lungs (0.64).

4.13 The gonadal dose equivalent rate (AGDE)

It is generally agreed that the bone surface cells, bone marrow and gonads are the utmost crucial organs. AGDE was calculated by below-given equation[13] (15):

$$AGDE(\mu Sv\ y^{-1}) = 3.09 \times A_{Ra} + 4.18 \times A_{Th} + 0.314 \times A_K \quad \ldots(15)$$

The limited value[13] of AGED for safe use is 300 mSv y^{-1}.

4.14 Cancer risk

Excess lifetime cancer risk (ELCR) is calculated using equation[26,27] (16):

$$ELCR = AEDE \times DL(65\ \text{years}) \times RF(\text{ICRP 60, 1990 uses } 0.05\ Sv^{-1}) \quad \ldots(16)$$

4.15 Clark value

This relation $^{232}Th/^{238}U$ i.e. concentration ratio of thorium to uranium may provide an indicator as to whether the specimens received from a certain site have a more or less uranium percentage to be economically viable for the exploitation and production of uranium[13].

5 Results and Discussion

The distribution of primordial radionuclides in parent rocks and the weathering procedures that accumulate them in different matrices of our surroundings affect the distributions of ^{226}Ra, ^{232}Th, and ^{40}K in rocks and further in soil. Igneous rocks, especially those containing dark-coloured heavy minerals, have higher radiation levels than sedimentary rocks. Major contributors to the higher natural background radiation are ^{232}Th in monazite sands, ^{238}U in soil and rocks, and their decay products[16, 17]. Phosphate rocks can release radioactive particles into the environment through several pathways[17].

Some of these pathways include the use of phosphogypsum in building and farming, as well as the application of fertilizers to agricultural fields. Thus, radiation protection, geoscientific studies, and the establishment of guidelines for the alleviation of these radionuclides all can be benefit from an organized study carried out for quantification of the levels of these radioactive elements (^{226}Ra, ^{232}Th, and ^{40}K) and their associated health risks for humans.

5.1 NORM's concentration in study area surface soil:

To ensure the long-term safety of people and the environment, regular monitoring of radioactivity is essential. Even if monitoring has been conducted previously in a region, it must be continued as levels of radioactive materials in the environment can vary over time due to a variety of factors such as natural disasters, human activities, and weather conditions. Continuous radioactivity monitoring is beneficial in identifying any changes in radioactivity levels and potential sources of radioactive materials, which enables timely interventions to prevent exposure and minimize risks to public health and the environment. Furthermore, ongoing monitoring helps to establish a baseline of radioactivity levels in an area, which can be used for future comparisons and as a reference for decision-making.

The concentration range and mean with other statistical parameters of naturally occurring radioactive elements quantified from the surface soil samples in the present investigation are given in Table 1. The purpose of this analysis is to determine whether or not certain radioactive substance is present in the study area, which provides the geological description of the research area. In almost all the soil samples, the specific activities were in the following order: $^{40}K > ^{238}U > ^{232}Th$. The mean estimated concentrations of ^{40}K, ^{226}Ra and ^{232}Th were comparable with the similar work carried out by

Table 1 — Statistical values of natural radioactivity concentration and radium equivalent in the top soil of Hisar and Fatehabad districts, Haryana, India

	Minimum	Maximum	Median	Mean	SD	Geo Mean	Geo SD	Variance	Coefficient of variation	Skewness	Kurtosis
Ra-226	31.60	53.20	42.40	42.57	3.81	42.40	1.09	14.50	0.09	0.00	0.35
Th-232	23.30	40.60	33.40	33.43	2.82	33.31	1.09	7.95	0.08	-0.17	0.83
K-40	402	610	496	500	39	498	1.08	1516	0.08	0.31	0.20
Ra eq	114	148	128	129	6.53	129	1.05	43	0.05	0.36	0.09

Table 2 — Global concentration of natural radioactivity (Bq kg^{-1}) and radium equivalent (Bq kg^{-1}) in soil samples

Area/ Country	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}
Punjab and Himachal, India[33]	57	87	143	192
Garhwal, India[34]	76	106	980	303
Kalpakkam, India[35]	23	93	434	189
Karnal, Northern Haryana, India[36]	52	187	1332	422
Palwal, Southern Haryana, India[37]	40	63	523	166
Central Haryana[43]	27.9	34	306	97.98
Aravali Hills[44]	12.15	45.17	639.24	125.96
Northeastern Haryana[45]	65	88.4	744.5	248.4
Egypt[38]	17	18	320	67
USA[13]	40	35	370	118
China[39]	32	41	440	124
Japan[13]	33	28	310	97
Malaysia[40]	66	82	310	207
Saudi Arabia[41]	15	11	225	48
Turkey[13]	86	51	772	218
Iran[42]	28	22	640	109
Algeria[13]	30	25	370	-
Portugal[13]	44	51	840	
Norway[13]	104	62	1058	276
Finland[13]	78	62	962	241
Netherland[13]	39	41	560	141
Greece[13]	25	21	360	-
Sri Lanka[13]	35	72	585	183
Kuwait[13]	7	7	332	42
Bangladesh[13]	29	52	292	127
Pakistan[13]	45	61	692	187
World Average[13]	35	30	400	-

other researchers in India and other nations (Table 2). The results demonstrate that ^{226}Ra(U-238) ranged between 31.59 and 53.23 Bq $kg^{-1}$and the mean values of uranium in the surface soil samples were calculated equal to 42.57± 3.81 Bq kg^{-1}. The maximum value of uranium was determined in the sample ID F-30 (F- Fatehabad) and the minimum was quantified in the soil sample ID F-13. The measured values (min-max and mean) of ^{232}Th in Bq kg^{-1} are given in Table 1. The maximum value of 40.61 ± 1.45 Bq kg^{-1} was in soil sample ID F-30 and the minimum was found in soil sample ID F-25 with the activity value of 23.26 ± 0.98 Bq kg^{-1}. However, the average value for ^{232}Th was estimated to be 33.43 ± 2.82 Bq kg^{-1}. In general, a high level of ^{40}K was observed in the surface soil samples collected during this study. This may be a result of phosphate fertilizers used by farmers or geological formations underlying the study area. The average value for ^{40}K content determined was 500 ± 39 Bq kg^{-1}. The results suggest that ^{40}K is the single most important contributor to total activity in the investigated area. The values of Ra_{eq} activity concentration ranged from 114 to 148 Bq $kg^{-1,}$ which is well within the prescribed limits; it means soil can also be used for dwelling construction.

In comparison to the study by Kansal *et al*.[28] in the Hisar district, the current study found higher activity concentrations for ^{226}Ra and ^{232}Th, but a lower concentration for ^{40}K. Similarly, the study by Mehra *et al*.[29] in the Sirsa district reported lower activity

concentrations for all three radionuclides. Another study by Kansal *et al.*[30] in western Haryana reported a wider range of activity concentrations for all three radionuclides, with higher maximum values than the current study. Finally, the study by Duggal *et al.*[31] in the adjacent area of northern Rajasthan reported lower activity concentrations for ^{226}Ra and ^{232}Th, but a higher concentration for ^{40}K than the current study.

Overall, these results highlight the variability in activity concentrations of radionuclides in soil samples within the region and the importance of conducting regular monitoring to ensure public health and environmental safety.

The Clark values determined in the present work are less than one. This is the case when uranium content in soil is greater than the thorium content. However, observed values are very near to one, which reveals that it is not economical to extract uranium from the soil of the investigated area.

Charts showing frequency distributions used to test for the normality of the data sets for ^{226}Ra, ^{232}Th, ^{40}K and Ra_{eq} and patterns were shown to be multimodal for ^{232}Th and ^{40}K and unimodal for ^{226}Ra and Ra_{eq}. In Fig. 3, the flattering plots of the histograms illustrate that the distribution of radioactive elements was not even. All were slightly skewed, but potassium's skewness was much bigger than that of uranium and thorium. The skewness factor had a meaningless value, which showed that the radium or uranium was symmetrical in the middle, while the kurtosis factor had a small but noticeable value. The ^{226}Ra histogram showed that the activity concentration class was most likely to have an occurrence between 42 and 44 Bq kg^{-1}. When the summary statistics for ^{232}Th were worked out, there were small differences. Its values are skewed towards higher values. A comparatively higher value of skewness for ^{40}K indicates deviation from a normal distribution and the same has been confirmed by histogram.

5.2 Dose Rates due to radioactivity in soil

Table 3 shows the different exposure and dose criteria that were calculated and some others are given in Fig. 4. When compared to outdoor levels, AEDE values are consistently greater than indoors. All samples have lower levels of AGDE and ELCR than the allowed maximum. The exposure rate (ER) at one meter above the surface level varied 234 – 301 μRh^{-1},

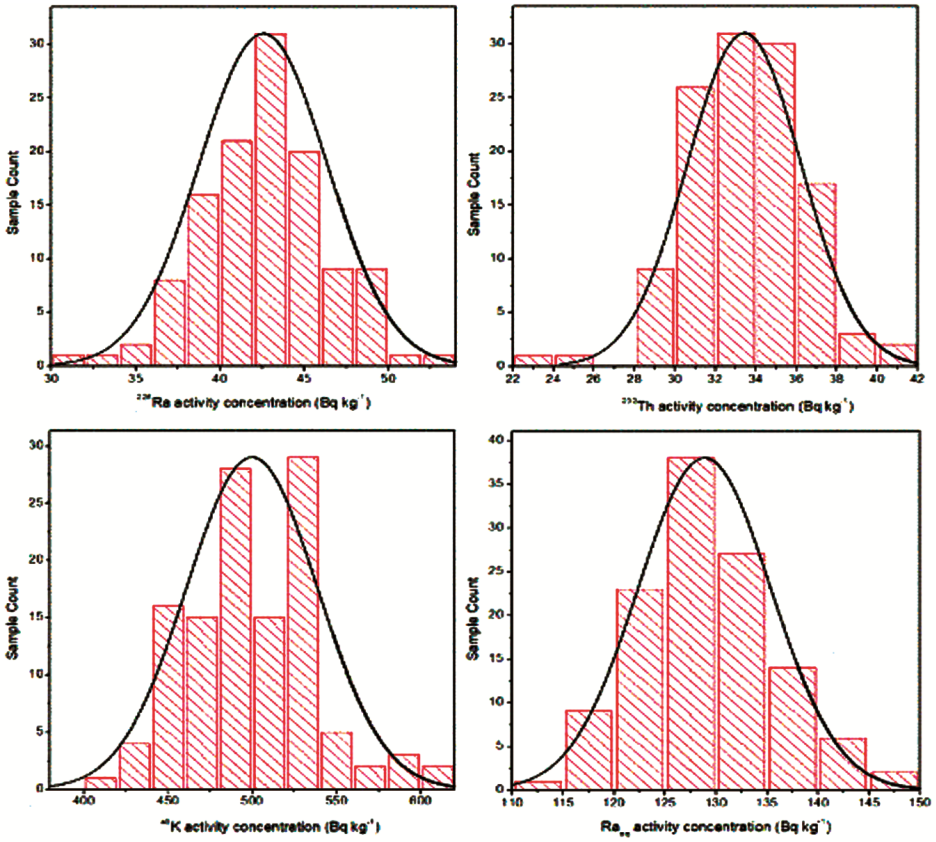

Fig. 3 — Histogram representation of activity concentration

Table 3 — Range and average values of different doses due to natural radioactivity in soil

	Exposure rate	Relative Dose rate	Air Absorbed Dose	Annual effective dose equivalent(μSv y^{-1})			The gonadal dose equivalent rate	Lungs	Ovaries	Bone marrow	Testes	Whole body
	(μRh^{-1})	(mrem y^{-1})	(nGyh^{-1})	Out	In	Total	(μSv y^{-1})	(μSvy^{-1})	(μSv y^{-1})	(μSv y^{-1})	(μSv y^{-1})	(μSv y^{-1})
Minimum	234	19	54	67	266	332	379	213	193	229	273	226
Maximum	301	25	70	86	343	428	484	274	248	295	351	291
MEAN	265	22	61	75	301	376	428	241	218	260	308	256
SD	13	1	3	4	15	19	21	12	11	13	15	13

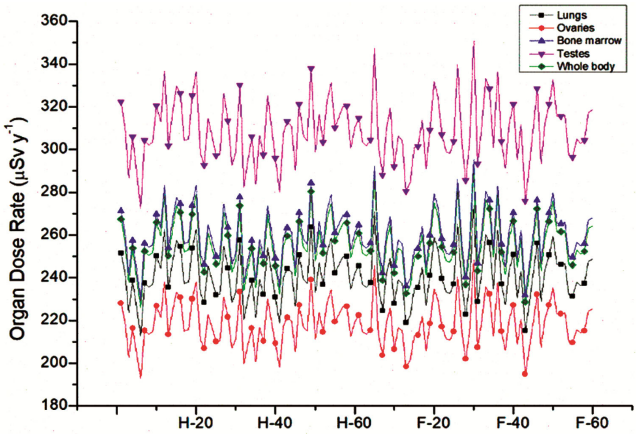

Fig. 4 — Effective dose rate (D_{organ}) to different body organs and tissues due to soil radioactivity

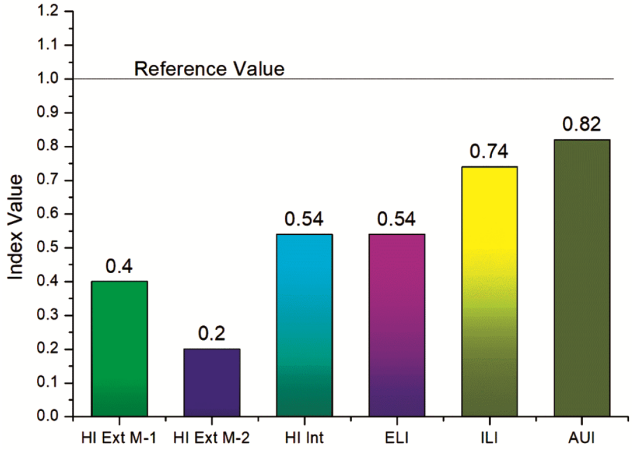

Fig. 5 — External and internal hazard indices, external and internal level indices and alpha utilization index (max values only) due to radioactivity in soil.

the dose rate (DR) due to this exposure ranged 19 – 25 mrem y^{-1}, air absorbed dose (AAD) rate ranged 54 - 70 nGy h^{-1} similarly AEDE and AGDE varied 332 – 428 μSv y^{-1} and 379 – 484 μSv y^{-1} respectively.

The risk of both random and predetermined consequences in exposed individuals is quantified by AEDE. The yearly effective dose equivalent should be no more than 0.48 mSv y^{-1}, and the yearly effective dose equivalent[13] (indoors + outdoors) should be no more than 1 mSv y^{-1}. When a home has activity levels of ^{226}Ra, ^{232}Th, and ^{40}K, 35, 35, and 370 Bq kg^{-1}, respectively. UNSCEAR has established a baseline value of 300 mSv y^{-1} for AGED.

Dose rates for specific human organs have been given in Table 3 and Fig. 4. It is evident from the figure that testes have maximum and ovaries have less exposure to gamma radiations emitted from soil. The energies of interest in the present work are 0.2–3.0 MeV but authors used conversion factor 'f' to convert air dose to organ dose and this is almost independent of energy. ELCR values are also well within the limits.

5.3 Risk Analysis

Plenty of risk indices and level indices *viz.,*external and internal hazard indices, external and internal level indices and activity utilization index, *etc.* were calculated to check the potential threat due to radioactivity in soil. In all soil samples, these indices have a value of less than one (Fig. 5) which reflects that there is no potential threat due to the use of this soil in construction and residing on it. To figure out how the measured radiological parameters are related to each other and how strongly they are linked, Pearson's correlation coefficient analysis is used, and the results are shown in Table 4 as a linear correlation matrix. From this table, it can be seen that there is a strong positive correlation between the three radionuclides and all of the radiation hazard parameters. Ononugbo *et al.*[32] found a similar trend. So, these connections show that all three radionuclides are involved in the release of gamma radiation everywhere. Radiation hazard parameters correlate better with ^{226}Ra than ^{232}Th, as can be seen from the table, by comparing the two sets of numbers. Also, the correlation values for ^{40}K are lower than those

Table 4 — Correlation coefficients of natural radioactive elements and related dose equivalents.

	^{226}Ra	^{232}Th	^{40}K	Ra_eq	Exposure rate	Annual effective dose equivalent	The gonadal dose equivalent rate
^{226}Ra	1						
^{232}Th	0.267**	1					
^{40}K	-0.044	-0.180*	1				
Ra_eq	0.729**	0.691**	0.322**	1			
Exposure rate	0.694**	0.661**	0.399**	0.996**	1		
Annual effective dose equivalent	0.712**	0.638**	0.405**	0.996**	0.999**	1	
The gonadal dose equivalent rate	0.689**	0.609**	0.459**	0.989**	0.997**	0.998**	1

**. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed).

for ^{232}Th and ^{226}Ra. That means that the effects of ^{226}Ra on radiation danger are stronger than those of ^{232}Th and ^{40}K, respectively.

6 Conclusion

Investigation for the dose-response relationships of radioactive materials has been crucial in expanding our understanding of the dangers posed by radiation and drafting effective radiation protection policies. The data was compared to the UNSCEAR reference value and to values from other researchers around the globe. To determine the likelihood of uranium deposition, authors computed the isotopic values of these radioactive elements. The correlations between radionuclides and radiation danger indices are also studied statistically. In addition, the results of this analysis could be used as a benchmark against which future studies of ambient radiation changes can be compared. From the experimental and computational work on natural radioactivity in soil samples of Hisar and Fatehabad, we can conclude the following;

1. Soil samples from this area have been found to contain radionuclide levels higher than, comparable to, and lesser than the permitted levels.
2. ^{40}K has maximum activities this may be attributed to phosphate fertilizers or geological formation.
3. There is less Ra_{eq} than is permitted everywhere in the globe.
4. Testes are exposed maximum and ovaries minimum due to radiations in air.
5. All three indices—hazard, level, and activity utilization—fall below internationally recognized standards.
6. The Clark value is close to one, which means that the area where we took soil samples is not a good place to mine or extract uranium because it would not be worth it.

Acknowledgement

The authors acknowledge the support of the Board of Research in Nuclear Sciences, Department of Atomic Energy (BRNS-DAE), GoI, India for funding this study.

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