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Assessment of Radiological Doses from the Presence of ^{226}Ra, ^{232}Th and ^{40}K in the Soil Samples of Nawanshahar and Rupnagar Districts of Punjab (India)

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Apart from Uranium (^{238}U), other natural radionuclides such as radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) are considered to be carcinogenic due to their major contribution of radiological doses to human beings. This study revealed the measurement of primordial radionuclides (^{226}Ra, ^{232}Th, ^{40}K) from the Nawanshahar and Rupnagar districts of Punjab by using a gamma beta spectrometer. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the studied region was ranged from 18 ± 5 Bq kg^{-1} to 37 ± 6 Bq kg^{-1}, 23 ± 5 Bq kg^{-1} to 54 ± 8 Bq kg^{-1} and 273 ± 23 Bq kg^{-1} to 472 ± 37 Bq kg^{-1} respectively. The distinct radiation hazards parameters as radium equivalent (Ra^{Eq}), absorbed dose rate (AD) and annual effective doses (AEDE) were estimated for radiological risk assessment. The absorbed dose levels of ^{226}Ra, ^{232}Th and ^{40}K in the studied area ranged from 8.74 nGyh^{-1}-15.33 nGyh^{-1}, 14.6 nGyh^{-1}-33.7 nGyh^{-1}, and 11.31 nGyh^{-1} -18.93 nGyh^{-1}, respectively. The annual effective doses in the studied region were 0.32 mSv y^{-1} (indoor) and 0.8 mSv y^{-1} (outdoor), respectively. The estimated hazard indices in the studied region were below unity showing that exposure to natural radionuclides in the soil is not a problem in the areas from a radiation hazards point of view.

Keywords: Radium; Thorium; Potassium; Radiological doses; Risk assessment; Toxicity

1 Introduction

Soil is a natural source of different heavy metals and radionuclides. Umpteen anthropogenic activities are also responsible for the presence of these radioactive isotopes and heavy metals in different vicinities. These isotopes can originate from a number of different sources, such as volcanic eruptions, cosmic radiation, and human activities like nuclear power production and testing of nuclear weapons, and their higher concentration can pose a severe risk to the environment and human health. Primordial radionuclides have existed since the formation of the earth decayed over time. These elements are still present due to their long half-lives and are situated chiefly within rocks, organic material, minerals, organisms and, subsequently, inside the soil, water and in air vicinities. These toxicants contaminated the different mediums and further migrate to large distance in the ecosystem. Uranium, thorium, and radium are a few of the most prevalent radionuclides found in soil; these are naturally occurring elements that are present in minute levels in a variety of rocks. Other radionuclides, such strontium-90 and cesium-137, are essentially the result of human activity, like the production of nuclear energy and weapon testing.

Soil is mainly formed by rocks due to numerous environmental conditions such as climatic changes, variations in temperature, weathering *etc*. The rock weathering leads to the deposit radionuclides in the nearby soil, and further transfer to different vicinities. Inherent property of soil is responsible for the migration, distribution, and concentration of radionuclides in soil[1-5]. The higher concentration of these radionuclides in any medium is a threat to human beings and is responsible for the radiological doses received by the inhabitants of particular regions[6-11]. Radionuclides in soil can have a variety of detrimental effects on both human health and the environment as the exposure to high radionuclide concentrations can raise the chance of developing cancer, genetic mutations, and other health issues[7-11]. The presence of these toxicants in certain permissible

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limits in the soil can also cause health hazards as the cancers of the kidney, prostate and other types of ailments as leukemia and melanoma[7]. In order to reduce the hazards posed by radionuclides in soil, it is crucial to be aware of these risks. A few regions worldwide have higher radiation background areas due to local radionuclide-rich rock formation and geothermal effects that can cause a high level of primordial radiation.

Various technologies can be used to reduce the dangers posed by radionuclides in soil. To lessen the exposure of radionuclides, physical techniques can be applied, such as excavation and soil removal from polluted areas. Moreover, certain chemical techniques can be used, such as soil washing, when toxins are dissolved and removed from the soil. Another alternative is "bioremediation," which involves using microorganisms to breakdown and break down radionuclides in the soil. This has been proven to be an efficient natural way to remove radioactive pollutants from soil. However, for majority of remediation techniques in soil vicinities are limited up to research laboratories and difficult to apply in acres of land. Household in India is mainly made up of bricks which are 80% mixed with soil, which contains a higher concentration of radionuclides[7]. Every building material includes a significant amount of radionuclides in different quantities. The gamma radiations and ^{222}Rn decay products are responsible for external and internal exposure[8,12-14]. The Punjab region is the backbone of agricultural activities and is known to be the bread basket of India. The five green revolutions of India enriched the Punjab region with wheat, grains and cotton. Over the last six decades, pesticides and fungicides have been used on a large scale in order to sustain the agricultural environment in this province. Southern Punjab's region is already highlighted for elevating the concentration of different radionuclides and heavy metals due to rock formation and other anthropogenic activities[15]. Furthermore, urbanisation and industrial growth continuously released many contaminants in air, water and soil vicinities. The present study assessed radiation hazards, annual doses and radiological risks from the soil samples of the Narwanshahar and Rupnagar districts of Eastern Punjab (India).

2 Geology

Nawanshahar and Rupnagar are two districts (76°19′00″ and 76°45′00″, 30°44′00″ and 31°25′00″) located in the Eastern part of the Punjab State (India), a part of the Bist-Doab region. The area is surrounded by Siwalik hills on the northeast side, Kapurthala district in the northwest, Hoshiarpur district in the north, Sutlej River in the south and Jalandhar on the west side of communities. The whole geographical area is covered by 1190 sq. km. Nawanshahr district was separated from the Hoshiarpur and Jalandhar districts of Punjab. Geomorphologically, the site can be divided into alluvial fans and alluvial plains. The reddish chestnut and tropical arid brown soil are primarily found in these regions.

3 Methodology

The samples (soil) were taken from the various locations of Nawanshahr City and Rupnagar regions of Punjab, India. The samples were taken from a location where the soil was undisturbed. Generally, the soil is collected from a depth of 100 to 150 mm to reduce the influence of routine anthropogenic activities. Three to four bulk soil samples with a weight of 1 to 1.5 kg were taken from each sampling site. Soil samples were dried up in an oven (24 h at 100 °C) and then crushed into a fine powder using a pestle and mortar. The soil samples will further pass through the sieve of mesh size 150 μm and then packed in an airtight container (for three months) to maintain the equilibrium for ^{226}Ra and its decay products.

The activity concentration of different radionuclides were estimated by multi-channel NaI (Tl) Gamma Beta spectrometer (63 mm×63 mm) of ATOMTEX (AT1315). The activity concentration in soil samples have been determined from gamma energy of 1764 KeV, 2610 KeV and 1460 KeV, respectively. Measurement of natural radioactivity in different samples was further dependent upon various parameters such as mass, sample geometry, time of counting and detector's efficiency. The detection limit of the gamma beta spectrometer for radium, thorium and potassium was 3 Bq kg^{-1}, 3 Bq kg^{-1} and 30 Bq $kg^{-1,}$ respectively.

4 Results and Discussion

Descriptive statistical methods have been used to analyse and interpret the radionuclides data of the Nawanshahar and Rupnagar regions of Punjab (Table 1 and Table 2). The mean, range, standard deviation, variance, skewness (data symmetry distribution) and kurtosis (data tailness) has been discussed in Table 2. The (S_k) skewness of ^{226}Ra, ^{232}Th and ^{40}K showed highly skewed data with mean values of -0.09, 0.18 and 0.09, respectively (Table 2). The Kurtosis(K) of

Table 1 — The activity concentration of Ra -226, Th-232 and K-40 in Nawanshahr and Rupnagar districts of Punjab (India)

S. no	Districts	Sample location (Village)	Ra-226 (Bq kg^{-1})	Th-232 (Bq kg^{-1})	K-40 (Bq kg^{-1})	Ra^{Eq}	AED (m Sv)		Hazard Indices		Absorbed dose (nGyh^{-1})			Total
							Indoor	Outdoor	H^{Ex}	H^{Ex}	Ra	Th	K	
1	Nawanshahar City	Nawanshahar City	32 ± 5	48 ± 6	365 ± 23	126.59	0.29	0.07	0.35	0.44	14.76	30.06	15.13	59.95
2		Balachaur	23 ± 4	54 ± 8	398 ± 28	128.87	0.3	0.07	0.36	0.42	10.82	33.77	16.49	61.08
3		Rahon	22 ± 6	51 ± 5	400 ± 30	123.99	0.29	0.07	0.34	0.40	10.58	31.82	16.56	58.96
4		Aur	32 ±5	45 ± 6	333 ± 28	119.72	0.28	0.07	0.33	0.42	14.76	28.05	13.8	56.61
5		Banga	27 ±4	36 ± 5	457 ± 25	110.58	0.26	0.07	0.31	0.38	12.48	22.44	18.93	53.85
6		Jainpur	24 ± 6	40 ± 5	349 ±21	107.46	0.25	0.06	0.3	0.36	11.26	25.53	14.45	51.24
7		Behram	18 ± 5	52 ± 7	402 ±34	121.49	0.28	0.07	0.34	0.39	8.74	32.41	16.65	57.8
8		Mahelgela	29 ± 5	53 ± 5	365 ±30	130.93	0.3	0.08	0.36	0.44	13.54	33.11	15.12	61.77
9		Kathgarh	33 ± 4	53 ± 8	398 ± 27	137.48	0.32	0.08	0.38	0.47	15.27	33.32	16.49	65.08
10		Pojewal(Nawagraon)	31 ± 5	44 ± 9	472 ± 37	127.43	0.3	0.08	0.35	0.44	14.3	27.61	19.54	61.45
11		Mohanmajra	21 ± 4	53 ± 6	380 ± 32	124.7	0.29	0.07	0.34	0.40	9.85	33.4	15.77	59.02
12		Moranwali	28 ± 8	42 ± 5	425 ±26	119.65	0.28	0.07	0.33	0.41	13.19	26.69	17.61	57.49
13		Bassali	19 ± 4	37 ±9	438 ± 31	103.43	0.25	0.06	0.29	0.34	8.96	23.23	18.14	50.33
14		Jalwaha	27 ± 4	46 ± 6	315 ±28	116.33	0.27	0.07	0.32	0.39	12.61	29.16	13.03	54.8
15		Apra	25 ± 5	48 ± 8	395 ± 31	122.49	0.29	0.07	0.34	0.41	11.83	30.12	16.37	58.32
16	RupNagar	Morinda	23 ±7	25 ± 4	401 ± 24	87.42	0.21	0.05	0.24	0.33	10.72	15.72	16.61	43.05
17		Kurali	30.24	29 ± 7	300 ±32	93.19	0.22	0.05	0.26	0.35	13.94	18.27	12.43	44.64
18		Chatauli	21 ± 4	23 ± 5	279 ± 24	73.97	0.18	0.04	0.21	0.26	9.69	14.55	11.57	35.81
19		Bhatha Sahib	33 ± 5	40 ± 7	339 ±32	114.53	0.27	0.07	0.32	0.41	15.33	25.05	14.06	54.44
20		Rupnagar City	33 ± 7	23 ± 5	273 ±23	85.84	0.2	0.05	0.24	0.33	15.31	14.6	11.31	41.22
21		Ghanauli	32 ± 8	29 ± 5	299 ± 20	95.2	0.22	0.06	0.26	0.33	14.87	18.3	12.39	45.56
22		Bharatgarh	20 ± 3	30 ± 6	302 ±26	84.71	0.2	0.05	0.23	0.29	9.37	18.83	12.52	40.72
23		Nirmohgarh	28 ± 6	28 ± 8	340 ± 22	92.38	0.22	0.05	0.26	0.33	13.02	17.59	14.05	44.66
24		Kiratpur	36 ± 5	27 ± 6	342 ±28	99.24	0.23	0.06	0.27	0.37	16.71	17.06	14.09	47.86
25		Anandpur Sahib	33 ± 4	30 ± 5	333 ±34	99.74	0.24	0.06	0.28	0.37	15.32	18.81	13.79	47.92
26		Mirzapur	34 ± 6	31 ± 7	347 ± 19	104.41	0.25	0.06	0.29	0.38	15.99	19.79	14.38	50.16
27		Bindrakh	24 ± 6	26 ± 4	362 ±34	87.53	0.21	0.05	0.24	0.31	11.19	16.5	15.02	42.71
28		Shamaspur	19 ± 4	34 ± 9	406 ±25	97.1	0.23	0.06	0.27	0.32	8.92	21.47	16.83	47.22
29		Ganguwal	37 ± 5	32 ± 7	398 ±26	111.65	0.26	0.07	0.31	0.41	17.14	20.29	16.5	53.93
30		Jatana	27 ± 8	24 ± 5	361 ± 33	88.4	0.21	0.05	0.25	0.32	12.84	15.34	14.98	43.16

Table 2 — Radionuclide concentrations and their statistics in the area.

Radionuclide	Minimum	Maximum	Range	Variance	Std. Dev	Kurtosis (K)	Skewness (S)
Ra-226	18	37	27	31	6	-1.18	-0.09
Th-232	23	54	38	112	11	-1.45	0.18
K-40	273	472	366	2558	51	-0.46	0.09
Ra^{Eq}	73.97	137.48	63.51	274.26	16.56	-1.08	-0.137

^{226}Ra, ^{232}Th and ^{40}K showed platykurtic distribution with mean values of -1.18, -1.45 and -0.46, respectively. The platykurtic behaviour showed an excess negative kurtosis with flat tails distribution around their mean values. The upper, lower and median quartiles were recorded using Tukey's hinges method (Fig. 1). Fig. 1 (Box Plot) revealed less variation in the ^{226}Ra and ^{232}Th as compared to ^{40}K, with some outliers in each case. Furthermore, the symmetrical distribution and normality of data have been assessed by QQ plots (Fig. 2) that revealed the non-normal distribution of all radionuclides with heavy-tailed data as per kurtosis values. In general, the natural phenomena's as the variation of radionuclides in indoor air, heavy metals, normalised difference vegetation index (NDVI), particulate matter and trace gases showed non-normalised distributions due to the presence of excess outlier and timely anthropogenic activities in the different vicinities[3,6,15-17].

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K varied from 18 ± 5 Bq kg^{-1} to 37 ± 6 Bq kg^{-1}, 23 ± 5 Bq kg^{-1} to 54 ± 8 Bq kg^{-1} and 273 ± 23 Bq kg^{-1} to 472 ± 37 Bq kg^{-1} with mean of 27 Bq kg^{-1}, 38 Bq kg^{-1} and 366 Bq kg^{-1} respectively (Table 1). The Activity concentration of ^{232}Th is higher than that of ^{226}Ra and lower than ^{40}K in most of the studied locations. As per the UNSCEAR, 2008[14], The global mean concentration of ^{226}Ra, ^{232}Th, ^{40}K is 32 Bq kg^{-1}, 45 Bq kg^{-1} and 420 Bq kg^{-1}. The ^{232}Th activity concentration was lesser than the world average activity concentration and greater than the other states of India.

In Punjab, the concentration of heavy metals, ^{238}U (Uranium), ^{222}Rn (Radon) concentration and its decay products are higher in the southern Punjab as compared to other regions of Punjab[6,15]. The concentration of ^{226}Ra, ^{232}Th and ^{40}K is also higher in the southern Punjab as compared to estimated concentration of ^{226}Ra, ^{232}Th and ^{40}K in the present study. The estimated

activity concentration of these radinuclides was lower than the other states of India (Himachal Pradesh, Haryana, Jharkhand, Maharashtra, Karnataka, Kerala) and world average activity concentration of ^{226}Ra. However, the ^{40}K activity concentration was greater than the World mean activity concentration of ^{40}K and also from other states of India (Table 3 and Table 4).

4.1 Radiological Doses and Hazards

Distinct following parameters were studied to estimate the overall radiological risk assessment in Nawanshahr and Rupnagar districts.

4.1.1 Radium equivalent activity (Ra^{Eq})

The specific activities of soil samples with different radionuclides concentrations are used to elaborate with a standard index as known as Radium equivalent (Ra^{Eq}). This index is globally used to estimate radiological hazards as per equation 1.

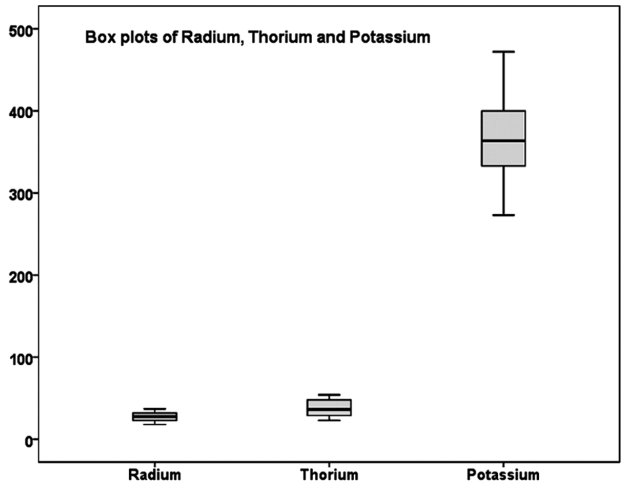

Fig.1 — Box plot of ^{226}Ra, ^{232}Th, ^{40}K.

$$Ra^{Eq} = C(^{226}Ra) + 1.43C(^{232}Th) + 0.07\ C(^{40}K) \quad \ldots(1)$$

where $C(^{226}Ra)$, $C(^{232}Th)$ and $C(^{40}K)$ are the activity concentrations of ^{226}Ra (Bq kg^{-1}), ^{232}Th (Bq kg^{-1}) and ^{40}K (Bq kg^{-1}), respectively. The Ra^{Eq} in the studied region varied from 74 Bq kg^{-1} to 137 Bq kg^{-1}and the average value is 108 Bq kg^{-1}. The mean value is lower than the recommended value (370 Bq kg^{-1}) given by OECD, (1979).

4.1.2 Air-absorbed dose rate (AD (nGy h^{-1}))

Terrestrial radionuclides are major contributors of gamma radiations.

The conversion factors of 0.0414 nGy h^{-1} Bq^{-1} kg^{-1} for ^{40}K, 0.461 nGy h^{-1} Bq^{-1} kg^{-1} for ^{226}Ra and 0.623 nGy h^{-1} for ^{232}Th by using equation 2.

$$AD\ (nGy\ h^{-1}) = 0.461\ C(^{226}Ra) + 0.623\ C(^{232}Th) + 0.0414\ C(^{40}K) \quad \ldots(2)$$

The rate of absorbed dose for ^{226}Ra, ^{232}Th and ^{40}K was varied from 8.74 nGyh^{-1} to 17.14 nGyh^{-1}, 14.60 nGyh^{-1} to 33.77 nGyh^{-1} and 11.31 nGyh^{-1} to 19.54 nGyh^{-1} respectively (Table 1). The total absorbed dose rate in the surved region lies between 35.80 nGyh^{-1} to 65.08 nGyh^{-1} with a mean value of 51.69 nGyh^{-1}. As per the reports of UNSCER (2008), the mean absorbed dose rate is lower than worldwide, and India's mean values are 86 nGyh^{-1} and 90 nGyh^{-1}.

4.1.3 Annual effective dose equivalent (AED)

The occupancy factor (20% external and 80% internal) with a conversion factor of 0.7 Sv Gy^{-1} was used to estimate the annual effective dose (Equations 3 and 4)

$$AED^{Indoor}\ (mSv\ y^{-1}) = AD\ (nGy\ h^{-1}) \times 8760\ h \times 0.8 \times 0.7(Sv\ Gy^{-1}) \quad \ldots(3)$$

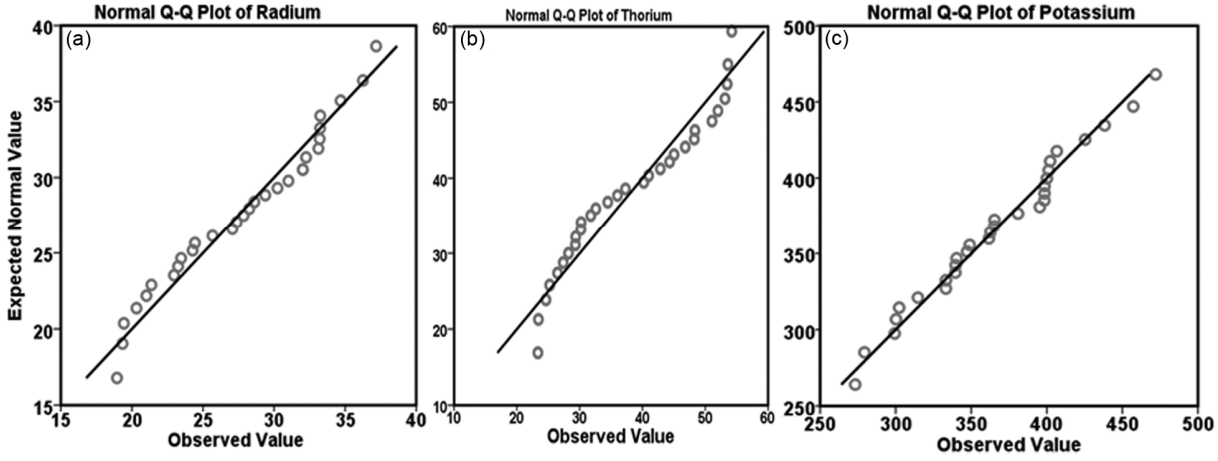

Fig. 2 — QQ plots ^{226}Ra (a), ^{232}Th- (b) and (c) ^{40}K.

Table 3 — Comparison of the activity of ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations ($Bqkg^{-1}$) found in soil samples in different Indian States.

S.Nos.no	Region	^{226}Ra ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)	Reference
1	Una, Himachal Pradesh	36.4–51.9	9.3–26.1	1361–1732	18
2	Siwalik region, Himachal Pradesh	8 - 3593	21 - 370	62-7130	3
3	Tumkur, Karnataka	9.6 – 71.6	12.3–333	194-1528	19
4	Coonor, Karnataka	41.5	78	295.6	20
5	Coastal Karnataka	20.1-62.3	14.3–48.6	61-316	21
6	Mandhya district, Karnataka	40.2	62.3	317.5	22
7	Thanjavur, Tamil Nadu	14.7	42.9	149.5	23
8	Kalpakam, Tamil Nadu	22.6	92.8	434.1	24
9	Jadugura, Jharkhand	53.8	44.2	464.2	25
10	Konkan, Maharashtra	45	59.7	217.5	26
11	Chavara beach, Kerala	170.4	547.3	117.2	27
12	Ludhiana, Punjab	28.58	50.95	569.59	28
13	Mana and Muktsar, Punjab	18-40	53-98	248-756	29
14	Barnala and Sangrur, Punjab	37	40	452	7
15	Sonipat, Haryana	41.5–54.9	31.4–37.9	463.8–696.9	30
16	Hisar, Haryana	17.8	45.5	360	31
17	Northern India	31–63	53–78	472–630	32
18	Chhatrapur, Orissa	120	2500	230	33
19	Visakhapatnam, Andhra Pradesh	20 ± 2–91 ± 2	45 ± 3–365 ± 3	400 ± 9–607	34
20	Narora, Uttar Pradesh	45.2	65.5	569.8	35
21	Delhi	30	20	200	36
22	Jaipur and Ajmer , Rajasthan	69	55	884	4

Table 4 — Worldwide activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in different parts of World.

S.No	Region	^{226}Ra ($Bq.kg^{-1}$)	^{232}Th ($Bq.kg^{-1}$)	^{40}K ($Bq.kg^{-1}$)	Reference
1	Chittagong, Bangladesh	65.9	83.17	946.9	37
2	Malaysia	1478	718	103	38
3	Egypt	8.64	13.77	141.64	39
4	Turkey	24.5	51.8	344.9	40
5	China	14.6	10.9	396.4	41
6	West Coast	1243	6257	647	42
7	Penang, Malaysia	31	36	369	43
8	World wide	35	30	400	13

$$AED^{Outdoor}\ (mSv\ y^{-1}) = AD\ (nGy\ h^{-1}) \times 8760\ h \times 0.2 \times 0.7(Sv\ Gy^{-1}) \quad \ldots(4)$$

Here AD ($nGy\ h^{-1}$) is an absorbed dose rate. The AED for indoor and outdoor were varied from 0.18 $mSv\ y^{-1}$ to 0.32 $mSv\ y^{-1}$ and 0.04 $mSv\ y^{-1}$ to 0.08 $mSv\ y^{-1}$with mean values of 0.25$mSv\ y^{-1}$ and 0.06 $mSv\ y^{-1}$ respectively.

4.1.4 External (H^{Ex}) and Internal (H^{In}) hazards indices

The H^{Ex} and H^{In} indices are worldwide accepted parameters to estimate the external radiation exposure from ^{226}Ra, ^{232}Th and ^{40}K and internal exposure from the carcinogen ^{222}Rn, respectively. The H^{Ex} and H^{In} can be calculated by using formulae (5) and (6).

$$H^{Ex} = C(^{226}Ra)/370 + C_{Th}/259 + C_K/4810 \quad \ldots(5)$$

$$H^{In} = C(^{232}Ra)/185 + C_{Th}/259 + C_K/4810 \quad \ldots(6)$$

The H^{Ex} and H^{In} in the studied region varied from 0.21 to 0.38 and 0.24 to 0.51, with mean values of 0.30 and 0.37, respectively. The mean value of these indices was lesser than unity, which revealed that the studied region is safe from the harmful effects of radiation hazards.

5 Conclusions

The present study depicts that the concentration of ^{226}Ra, ^{232}Th and ^{40}K in the surved area are differ from one place to another place with the average value are 28 Bq kg^{-1}, 38 Bq kg^{-1} and 366 Bq $kg^{-1,}$ respectively. The concentration of ^{232}Th is higher than ^{226}Ra in almost all the locations. Except for ^{40}K, the mean values of ^{226}Ra and ^{232}Th were lesser than the World mean concentration of ^{226}Ra, ^{232}Th and ^{40}K given by UNSCEAR, 2008. The excess use of fertilisers and pesticides in agricultural activities may be the reason for higher ^{40}K concentrations in the studied region. However, the mean value of Ra^{Eq} was found to be less

than the recommended value of 370 Bq kg^{-1}. Furthermore, the mean value of the absorbed dose rate in air, 51.69 $nGyh^{-1}$, is also lesser than the average world limit of 90 $nGyh^{-1}$ given by UNSCEAR, 2008. The radiation hazards and annual effective doses are within the range of recommended limit. The low value of radioactivity content in the soil of a studied region is good for the building material.

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