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Natural radioactivity levels (K, Th and Ra) in some areas of Punjab, India

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Abstract

Radioactivity, natural and man-made, is omnipresent in the earth's crust in different amounts. Natural radioactive materials under certain conditions can reach hazardous radiological levels. So, it becomes necessary to study the natural radioactivity levels in soil to assess the dose for the population in order to know the health risks and to have a baseline for future changes in the environmental radioactivity due to human activities. ^{226}Ra, ^{232}Th and ^{40}K analysis has been carried out in soil samples collected from some areas of Punjab, India using gamma-ray spectrometry. The technique of gamma ray spectrometry was applied using high purity germanium gamma-ray detector and a PC based MCA. Radium equivalent activities are calculated for the analyzed samples to assess radiation hazards arising due to the use of these soil samples in construction of dwellings. The measured activity in the soil ranges from 23.17 to 57.87 Bq kg^{-1}, 59.03 to 160.40 Bq kg^{-1} and 228.06 to 501.03 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K with mean values of 37.93, 84.47 and 351.17 Bq kg^{-1} respectively. It has been observed that on the average the outdoor terrestrial gamma air absorbed dose rate is about 84.65 nGy h^{-1}.

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1. Introduction

The world is naturally radioactive, and around 90% of human radiation exposure arises from natural sources such as cosmic radiations, exposure to radon gas, and terrestrial radiations. Natural radionuclides in rocks and soil generate a significant component of the background radiation exposure to human beings, which depend on the composition of the soils and rocks in which they are contained. A significant contribution to total dose from natural sources comes from terrestrial radionuclides such as ^{238}U, ^{232}Th and ^{40}K present in soil (Khan *et al.* 1998; Menon *et al.* 1982; Turhan *et al.* 2008). Since these radionuclides are not uniformly distributed, the knowledge of their distribution in soil and rocks plays an important role in radiation protection and measurement (Khan *et al.* 1994). The radiation dose comes from gamma-rays, which are emitted from rocks, soil and some building materials composed of the earth's crust. The estimation of exposures of humans to the various sources of radiation is important. Some of the exposures are fairly constant and uniform for all individuals everywhere for example, the dose from ingestion of ^{40}K in food. As radiation of natural origin is responsible for most of the total radiation exposure, knowledge of the dose received from natural sources is very important for not only of its effects on health but also of the incidence of other radiation from man-made sources (UNSCEAR 2000). The nuclides having half-life comparable with the age of earth or their corresponding decay products, existing in terrestrial materials, such as ^{40}K, ^{238}U and ^{232}Th radionuclides are of great interest.

Most of the developed and developing countries in the world are carrying out nation-wide surveys to assess the amount of radioactivity in order to establish possible radiological hazards and to take safety measures if necessary (Beretka and Mathew, 1985; Mollah *et al.*, 1986; Paredes *et al.*, 1987; Nazaro and Nero, 1988). Naturally occurring radionuclides of terrestrial origin (primordial nuclides) are present in various degrees in all media in the environment, including the human body. There have been many surveys to determine the background levels of the radionuclides in soils like igneous, granite and sedimentary. All of these measurements indicate that gamma-emitting radionuclides in ^{226}Ra, ^{232}Th series and ^{40}K, made approximately equal contributions to the externally incident gamma radiation dose to individuals in typical situations both indoor and outdoor. The present study was undertaken to measure the specific activity and the gamma-ray absorbed dose of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil samples of some areas of Punjab, India using gamma-ray spectrometry as it provides a fast and simple method of measuring the concentration

Figure 1: Map showing the area surveyed.

of natural and manmade radionuclides into the environment. The multi elemental and non-destructive character of this technique makes it superior over the other traditional techniques.

2. Geology of the area

Punjab state extends from the latitudes 29.30° to 32.32° North and longitudes 73.55° to 76.50° east. It is bounded on the west by Pakistan, on the north by Jammu and Kashmir, on the northeast by Himachal Pradesh and on the south by Haryana and Rajasthan. Due to the presence of a large number of rivers, most of the Punjab is a fertile plain. The southeast region of the state is semi-arid and gradually presents a desert landscape. A belt of undulating hills extends along the northeastern part of the state at the

foot of the Himalayas. The soil characteristics are influenced to a very limited extent by the topography, vegetation and parent rock. The variation in soil profile characteristics is much more pronounced because of the regional climatic differences. On the basis of soil types Punjab can be divided into three distinct regions; southwestern, central, and eastern. Southwestern Punjab, India, has been taken as region of interest in the present work. Our studies area consists of three districts of Punjab viz. Faridkot, Ferozepur and Muktsar (fig. 1).

Muktsar, with an area of 2615 km^2, which constitutes 5.19% of the area of Punjab, is situated in the southwestern zone of Punjab. It lies between 30° 69′ and 29° 87′ latitude and 74° 21′ and 74° 86′ longitude. It is bounded by the States of Rajasthan and Haryana in the South, district Faridkot in North, Ferozepur in West and Bathinda in the East.

Faridkot is situated between 29° 54′ to 30° 54′ latitude and 74° 15′ to 75° 25′ longitude. It lies in the southwest of the state and is surrounded by Ferozepur District in the northwest, Moga and Ludhiana Districts in the northeast and districts of Bathinda and Sangrur in the south. The District covers an area of 1469 km^2, which is 2.92% of the total area of the State and accommodates a population of 5, 52,466 which is 2.27% of the total population of the state.

The Ferozpur District lies between latitude 29° 55′ and 31° 09′ and between longitude 73° 53′ and 75° 24′. On the northeast, the river Satluj generally separates it from the Jalandhar and Kapurthala districts. The united stream of the Satluj and the Beas generally separates it from the Amritsar District in the northwest, and farther down from the Pakistan, with the exception of some areas on each side of the river.

3. Experimental procedure

3.1 Measurement of natural radioactivity

In order to measure the natural radioactivity in soil, surface soil samples were collected from different locations from three shown districts of Punjab, India namely Faridkot, Ferozepur and Muktsar. One sample from each location was collected by digging a hole at a depth of 0.5 m in the ground surface. After collection, samples were crushed to fine powder by using mortar and pestle. Fine quality of the sample was obtained using a scientific sieve of 100 micron-mesh size. Before measurement, samples were dried, packed, sealed in an airtight PVC container and kept for about 4 weeks to allow radioactive equilibrium between radon (^{222}Ra) and its short-lived decay products. An

average 0.25 kg of soil was used per sample. Using high purity germanium (HPGe) detectors based on a high-resolution gamma spectrometry system, the activity of soil samples was determined. The details of the technique are the same as reported elsewhere (Mehra *et al.*, 2007). The efficiency calibration for the system was carried out using secondary standards of uranium ore in the same geometry as for the sample counting. The secondary standard was calibrated with the primary standard (RGU-1) obtained from the International Atomic Energy Agency. Gamma transitions of 186 keV and 609 keV were used for ^{226}Ra, 1461 keV for ^{40}K, 338, 463, 911, 968 keV for ^{228}Ac, 727 keV of ^{212}Bi, and 238 keV of ^{212}Pb for ^{232}Th for the laboratory measurement of the respective activity concentration. The samples were counted for a period of 72,000 s each. A typical spectrum is shown in fig. 2. Based on the applied conditions, the achieved detection limits were 2 Bq kg^{-1}, 3 Bq kg^{-1} and 2 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The concentration of radionuclides was calculated using the following equation

$$\text{Activity(Bq)} = \frac{\text{CPS} \times 100 \times 100}{\text{B.I.} \times \text{Eff}} \pm \frac{\text{SD}_{\text{CPS}} \times 100 \times 100}{\text{B.I.} \times \text{Eff}} \tag{1}$$

where, CPS = Net count rate per second
B.I. = Branching ratio Intensity, and
Eff = full peak efficiency of the detector.

3.2 Radium equivalent activity

The radium equivalent activity was calculated through the following relation (Yu *et al.*, 1992)

$$\text{Ra}_{\text{eq}} = C_{\text{Ra}} + 1.43C_{\text{Th}} + 0.07C_{\text{K}} \tag{2}$$

where C_{Ra}, C_{Th} and C_{K} is the respective activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}. While defining the Ra_{eq} activity, it has been assumed that 370 Bq kg^{-1} ^{226}Ra or 259 Bq kg^{-1} ^{232}Th or 4810 Bq kg^{-1} ^{40}K produce the same gamma dose rate. The radium equivalent activity (Ra_{eq}) in these soil samples ranges from 136 Bq kg^{-1} in Faridkot to 310 Bq kg^{-1} in Sitoguno with a mean value of 183 Bq kg^{-1} which is less than the safe limit (370 Bq kg^{-1}) recommended by the Organization for Economic Cooperation and Development (OECD), (1979).

3.3 Calculation of annual effective dose

Annual estimated average effective dose equivalent received by the population was calculated using a conversion factor of 0.7 Sv Gy^{-1}, which was

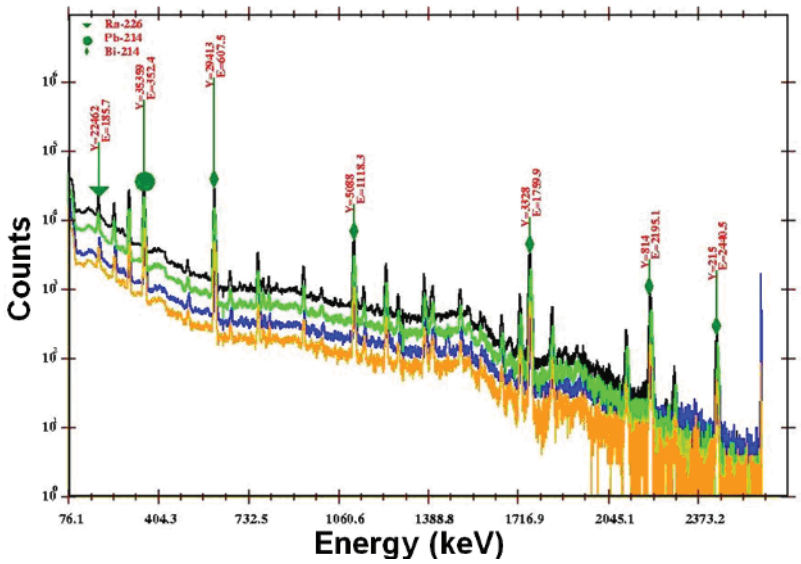

Figure 2: Gamma-ray spectra of samples showing various peaks of radionuclides.

used to convert the absorbed rate to human effective dose equivalent with an outdoor occupancy of 20% and 80% for indoors (UNSCEAR, 1993). The annual effective doses were determined as follows

$$\begin{aligned}\text{Indoor(nSv)} = {} & (\text{Absorbed dose})\text{nGyh}^{-1} \times 8760\,\text{h} \\ & \times 0.8 \times 0.7\,\text{SvGy}^{-1}, \qquad (3)\\ \text{Outdoor(nSv)} = {} & (\text{Absorbed dose})\text{nGyh}^{-1} \times 8760\,\text{h} \\ & \times 0.2 \times 0.7\,\text{SvGy}^{-1}, \qquad (4)\end{aligned}$$

3.4 External hazard index (H_{ex})

The external hazard index H_{ex} can be calculated using the following equation (Beretka and Mathew, 1985)

$$H_{\text{ex}} = \frac{C_{\text{Ra}}}{370} + \frac{C_{\text{Th}}}{259} + \frac{C_{\text{K}}}{4810} \leq 1, \qquad (5)$$

where C_{Ra}, C_{Th} and C_{K} is the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in $\text{Bq}\,\text{kg}^{-1}$, respectively. If the value of this index is less than unity, the radiation hazard is insignificant. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} ($370\,\text{Bq}\,\text{kg}^{-1}$).

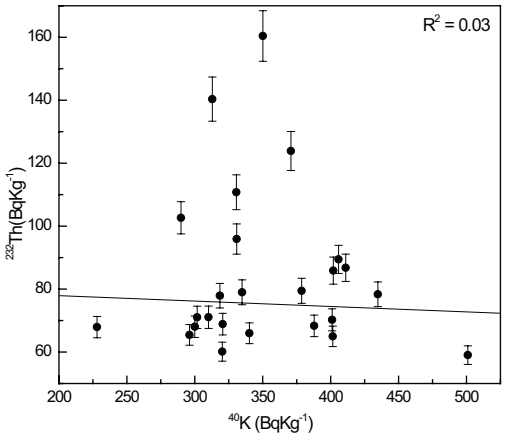

Figure 3: Variation of ^{232}Th with ^{40}K activity concentrations in the soils of the investigated area.

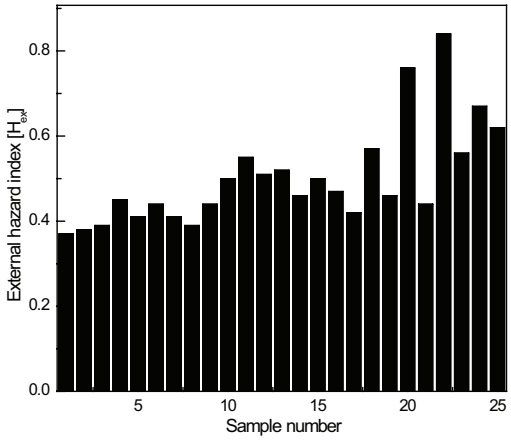

Figure 4: Bar diagram showing the values of the external hazard index at different locations in Punjab.

Table 1: Analytical results for the activity concentration of ^{226}Ra, ^{232}Th and of ^{40}K (Bq kg^{-1}) determined for each of the measured samples together with their total uncertainties, radium equivalent, external hazard index, total absorbed dose and effective dose rate at various locations of Northern Punjab, India.

S. No	Sample Location	Radium Concentration in Soil C_{Radium} (Bq kg^{-1})	Thorium Concentration in Soil $C_{Thorium}$ (Bq kg^{-1})	Potassium Concentration in Soil $C_{Potassium}$ (Bq kg^{-1})	Radium Equivalent	Absorbed Dose (nGy h^{-1})	Annual effective dose (mSv)		External Hazard Index (H_{ex})
							Indoor	Outdoor	
1	Faridkot	23.17	67.92	228.00	136.26	62.43	0.31	0.08	0.37
2	Sadik	24.12	65.45	296.14	138.44	64.15	0.31	0.08	0.38
3	Kot Kapura	34.23	60.12	320.23	142.62	66.49	0.33	0.08	0.39
4	Khara	40.9	71.06	310.12	164.22	75.96	0.37	0.09	0.45
5	Jaito	28.23	68.87	320.56	149.15	69.19	0.34	0.08	0.41
6	Machaki Kalan	26.72	77.89	318.45	160.39	74.03	0.36	0.09	0.44
7	Mani Singhwala	26.24	71.03	301.76	148.94	68.84	0.34	0.08	0.41
8	Gughiana	24.89	68.04	299.98	143.19	66.28	0.33	0.08	0.39
9	Sarawan	40.23	64.98	401.54	161.26	75.65	0.37	0.09	0.44
10	Muktsar	41.43	78.34	434.76	183.89	85.90	0.42	0.11	0.50
11	Virk Khera	45.56	89.43	405.87	201.86	93.52	0.46	0.11	0.55
12	malaout	33.07	86.76	411.08	185.91	86.32	0.42	0.11	0.51
13	Jurar	38.92	85.87	401.98	189.85	88.08	0.43	0.11	0.52
14	Badal	39.99	70.23	401.12	168.50	78.80	0.39	0.10	0.46
15	Giddarbaha	41.43	79.45	378.67	181.55	84.27	0.41	0.10	0.50
16	Abul Khurana	36.45	78.98	334.76	172.82	79.87	0.39	0.10	0.47
17	Jandwala	32.21	59.03	501.03	151.70	72.37	0.36	0.09	0.42
18	Ferozpur	42.56	102.65	289.85	209.64	95.57	0.47	0.12	0.57
19	Dangar Khera	42.62	68.32	387.91	167.47	78.27	0.38	0.10	0.46
20	Balluana	55.23	140.34	312.92	277.82	125.85	0.62	0.15	0.76
21	Abohar	43.72	65.98	340.23	161.89	75.35	0.37	0.09	0.44
22	Sitoguno	55.87	160.4	350.12	309.75	140.18	0.69	0.17	0.84
23	Khubban	43.81	95.89	330.84	204.09	93.63	0.46	0.11	0.56
24	Himmatpura	40.78	123.87	370.76	243.87	111.32	0.55	0.14	0.67
25	Radheywala Chak	45.87	110.76	330.65	227.40	103.84	0.51	0.13	0.62
max		55.87	160.40	501.03	309.75	140.18	0.69	0.17	0.84
min		23.17	59.03	228.00	136.26	62.43	0.31	0.08	0.37
ave		37.93	84.47	351.17	183.30	84.65	0.42	0.10	0.50
g.m.		36.87	81.47	346.65	179.06	82.84	0.41	0.10	0.49

4. Results and discussion

The measured values for the activity concentration of the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K together with their average values in soil samples of 25 locations in Punjab (Faridkot, Ferozepur and Muktsar) are reported in table 1. The world average concentration is 35, 30 and 400 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. In general, the average activity concentration of ^{226}Ra and ^{232}Th in soil of these areas is higher than the world figures reported in UNSCEAR (2000), whereas the activity for ^{40}K is under the safe limit. Comparatively high values of ^{226}Ra and ^{232}Th in soil samples from this area may be due to the Punjab sediments that derive from the Shiwalik Himalaya and occur in the form of Alluvium. Residential houses and dwellings in the investigated area were mostly built with bricks made of this soil. There exists information about cancers, average lifetime of people, typical health diseases, etc. in the area very close to the study area (Singh *et al.*, 1995, 2009). To assess the radiological risk of soil used as a building material, it was useful to calculate the radium equivalent activity and external hazard index (Orgun *et al.*, 2005; Beretka and Mathew, 1985). The values of radium equivalent activity (Ra_{eq}) around the investigated areas were less than the acceptable safe limit of 370 Bq kg^{-1} (OECD, 1979). The calculated total absorbed dose and annual effective dose rates of samples are also shown in table 1.

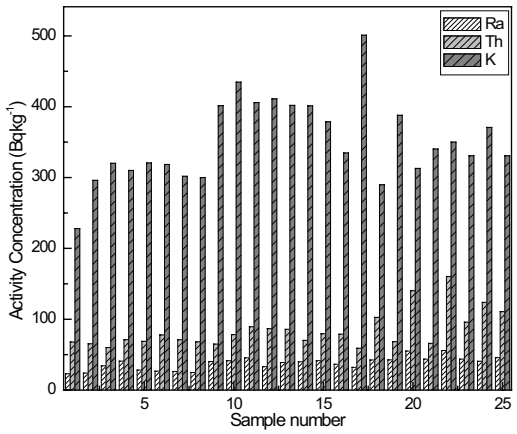

Figure 5: Bar diagram showing the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K at the different sampling sites.

Table 2: Characteristics of the gamma-ray spectrometer. Equations for elemental counts: Thorium $= C_3$, Radium $= C_2 - aC_3$, Potassium $= C_1 - bC_3 - c(C_2 - aC_3)$, where C_1, C_2 and C_3 are background subtracted true counts in K, Ra and Th energy bands, respectively, $a = 0.58$, $b = 0.72$, $c = 1.18$.

Parameter	For radio nuclides		
	^{226}Ra	^{232}Th	^{40}K
Gamma lines used (MeV)	1.76 (^{214}Bi)	2.62 (^{208}Tl)	1.46
Background reduction factor	12.3	15.4	18.5
Percentage efficiency	1.39	1.37	4.16
MDA (Bq kg^{-1}) for 120000 s counting time, (7.5 × 6.5) cm cylindrical plastic container geometry	8	7	5

The calculated total absorbed dose and annual effective dose rates of samples are also shown in table 1. The International Commission on Radiological Protection (ICRP) has recommended the annual effective dose equivalent limit of 1 mSv y^{-1} for the individual members of the public and 20 mSv y^{-1} for the radiation workers (ICRP, 1993). These dose limits have been established on the prudent approach assuming that there is no threshold dose below which there would be no effect. This means that any additional dose would cause a proportional increase in chance of a health effect. The world wide average annual effective dose is approximately 0.5 mSv and the results for individual countries being generally within the 0.3–0.6 mSv range (UNSCEAR, 2000). Table 2 gives the levels of the natural radionuclides in the soil samples of various other countries. When the present data for Punjab are compared to the ones worldwide, it is seen that the overall values of ^{40}K are in the lower range and the value of ^{226}Ra and ^{232}Th matches with those of the other countries. The highest values of radionuclides recorded (fig. 2) in the soil samples from the investigated area are originating from the Shiwalik Himalaya (composed of radioactive rich granites, sandstones and quartzites) and occur in the form of Alluvium. Plotting the activity of ^{232}Th as function of the ^{40}K activity of shows a poor correlation ($R^2 = 0.03$, $N = 25$) in the soil samples of the investigated area (fig. 3). The calculated values of H_{ex} for the soil samples range from 0.37 to 0.84 around the investigated area with an average value of 0.50 (table 1).

Table 3: Comparison of natural radioactivity levels in soil at different locations of Punjab (India) with those in other countries as given in UNSCEAR (2000).

Region/Country	Concentration in soil ($Bq\,kg^{-1}$)					
	^{226}Ra		^{232}Th		^{40}K	
	Mean	Range	Mean	Range	Mean	Range
Norway	50		45		850	
Malaysia	67	38-94	82	63-110	310	170-430
Egypt	17	5-64	18	2-96	320	29-650
US	40	8-160	35	4-130	370	100-170
Argentina					650	540-750
Bangladesh	34	21-43			350	130-610
China	32	2-440	41	1-360	440	9-1800
Hongkong	59	20-110	95	16-200	530	80-1100
India	29	7-81	64	14-160	400	38-760
Japan	33	6-98	28	2-88	310	15-990
Thailand	48	11-78	51	7-120	230	7-712
Korea,Republic of	-	-	-	-	670	17-1500
Iran (Islamic Rep. of)	28	8-55	22	5-42	640	250-980
Denmark	17	9-29	19	8-30	460	240-610
Belgium	26	5-50	27	5-50	380	70-900
Luxembourg	35	6-52	50	7-70	620	80-1800
Switzerland	40	10-900	25	4-70	370	40-100
Bulgaria	45	12-210	30	7-160	400	40-800
Poland	26	5-120	21	4-77	410	110-970
Romania	32	8-60	28	11-75	490	250-1100
Greece	25	1-240	21	1-190	360	12-1570
Portugal	44	8-65	51	22-100	840	220-1230
Spain	32	6-250	33	2-210	470	25-1650
Germany		5-200		7-134		40-1340
Hungary	33	14-76	28	12-45	370	79-570
Cyprus	17	0-120	-	-	140	0-670
Netherland	23	6-63	-	8-77	-	120-730
Present Study	37	23-55	59	59-160	351	228-501

Since all these values are lower than unity, according to the Radiation Protection report (European Commission, 1999), soil from these regions can be considered as safe and can be used as construction material without posing any significant radiological threat to the population (fig. 4).

5. Conclusions

1. The average activity concentration of ^{226}Ra and ^{232}Th in soil of these areas are higher than the world average figures reported in UNSCEAR (2000) whereas the concentration of ^{40}K is rather low (table 3, fig. 5).

2. High values of ^{226}Ra and ^{232}Th in soil samples from this area may be caused by Punjab sediments originating from the Shiwalik Himalaya. They occur in the form of Alluvium.

Acknowledgments

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