Evaluation of background radiation level and excess lifetime cancer risk in Doon valley, Garhwal Himalaya

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Abstract
Radionuclides such as Ra-226, Th-232 & K-40 occurs naturally in the earth crust from its creation and are main contributor to the dose received by human beings. The present study was carried-out in the Doon valley which is outlined in the Main Boundary Thrust (MBT) region of Garhwal Himalaya in Uttarakhand, India. The collected soil/rock samples were analyzed by NaI(Tl) Gamma ray spectrometry for the analysis of radionuclides and hence measuring the various health hazard indices and Excess lifetime cancer risk. Radionuclide (226Ra, 232Th & 40K) content were found to vary from 47 ± 9 to 442 ± 50 Bq Kg\(^{-1}\), 45 ± 17 to 101 ± 16 Bq Kg\(^{-1}\) & 320 ± 281 to 947 ± 197 Bq Kg\(^{-1}\) respectively and were higher than the world average values which are 35 Bq Kg\(^{-1}\), 30 Bq Kg\(^{-1}\) and 400 Bq Kg\(^{-1}\) respectively. Higher radionuclide content contributes to higher amount of absorbed doses which was found to vary from 93 to 259.6 ηGyh\(^{-1}\) with a mean value of 112.5 ηGyh\(^{-1}\) and Gamma index which found to vary from 0.73 to 1.92 with a mean value of 0.96. Lastly, on the basis of annual effective doses received to humanoid, Excess lifetime cancer risk was measured which varies from 0.48 × 10\(^{-3}\) to 1.34 × 10\(^{-3}\) with an average value of 0.65 × 10\(^{-3}\) and was much below the world’s average value of 1.45 × 10\(^{-3}\).

Keywords Main boundary thrust · Excess lifetime cancer risk · Natural radionuclide · Gamma index

Introduction
Human beings are coninously being exposed to both natural and artificial sources of radiation and are well classified into ionizing and non-ionizing radiations [1]. Ionizing radiations are energies with high frequency and have sufficient amount of energy to produce ions in a matter. If the matter is human being, these radiations results in sufficient amount of damage as compared to non-ionizing radiation in which the injury is limited to the thermal damage etc. These ionizing radiations affect human beings sometimes from the man-made sources while many a times from the natural sources present in our earth [2, 3]. Radioactivity in the universe existed since it was created by the process of big bang explosion.

The ionizing radiations is continuously being emitted by the building materials which include bricks, sand, stones, cement, concrete, marble, granite, gypsum, limestone etc. These building materials becomes prominent source of natural background radiation due to the presence of uranium (U-238), thorium (Th-232) along with their decay products and single decay radionuclide potassium (K-40) [2]. It is prominent that the radionuclides content in the earth crust contributes maximum in the annual dose received to the human being [1]. Emission of gamma radiations from these naturally occurring radionuclides are the principal source of exposure as compared to the alpha and beta radiations. The dose received to human beings are divided into internal and external exposure out of which the external exposure is due to the emission of gamma radiation from uranium, thorium and potassium whereas the internal exposure is because of the inhalation of radon, thoron and their decay products. The external doses recieved to human beings is prominently due
to the radioactivity level present in the rocks and minerals [4, 5].

Previously, several studies were carried out for the estimation of radionuclide content in various parts of the world and hence for evaluating a baseline data for their country so that the authorities may take significant steps for the safety of their citizens [6–14]. In continuation, there were numerous studies carried out in various states/parts of India depending upon variability in its lithology and geology [15–21]. These studies were necessary for estimation of various doses received to humanoids and hence analyzing the excess lifetime cancer risk [13, 16, 22, 23].

In the present manuscript, a study was carried out for the analysis of natural radionuclide (Ra-226, Th-232 & K-40) in the Maldevta region of Doon valley which is along the MBT region in Garhwal Himalaya, Uttarakhand. Thereafter, a comparison of natural radionuclides and their received doses was carried out in the present study area (Maldevta) with the Rajpur region (both falls in Doon valley and Main Boundary Thrust region) [21]. The spatial distribution graphs were plotted in order to understand the appropriate geology of the region using various statistical factors. With the analysis of natural radionuclides, we calculated equivalent radium activity (Ra_eq), external and internal health hazard indices (H_ex and H_in), absorbed dose (AD), Annual effective dose (E_in and E_out) and gamma index (γ in) which are significant for health point of view. At the Last, Excess lifetime cancer risk was evaluated which bring an idea about the safety and protection of inhabitants living in the study area.

Geology of the location

The sampling site chosen for the present study was Doon valley, located in the district Dehradun of Uttarakhand, India as shown in Fig. 1. The sampling location has a vast variation in its lithology due to deposition minerals and ores [24–28], as it falls over and near the Main Boundary Thrust (MBT) region. Secondly a very beautiful city is nurturing in its lap and the name of the city is Dehradun which is known for its pleasant weather and beauty. The city is one of the largest and most densely populated city in the Hilly state of Uttarakhand. Hence, the study is significant from health risk point of view for the citizens residing in the city. (Figs. 2, 3)

Himalayan Mountain range in India is a young fold mountain range which runs from state of Jammu & Kashmir in the west to the Arunachal Pradesh in the east. This mountainous belt is subdivided into four domains according to its geology and lithology which are named as Higher Himalaya (HH), Lower Himalaya (LH), Shivaliks (S) and the Indo-Gangetic plain (IGP) [29]. These four domains are separated by three south verging faults. The union between Lower Himalaya (LH) and Shivalik (S) is known as Main Boundary Thrust (MBT). MBT detaches the shivaliks which are the tertiary rocks to the Lower Himalaya which are the pre-tertiary rocks that are composed of krol, tal and infr-krol.

Doon valley consists of lower grade Meso-proterozoic rocks which are also called as Jaunsar group of formation while the Nagthath and Chandpur group of formation are the older groups in which the lower Palaeozoic mixed carbonate-siliciclastic are the succession of Blaini-krol and Tal while the Upper Neoproterozoic are the new ones. Along with this, a narrow line of marine cretaceous shell limestone and Eocene Subathu limestone is very much evident, which are the clay bands of thick pebbles and boulders usually known as Doon gravels [30]. Rajpur region is composed of phosphorite, chert, siltstone and carbonaceous shale which is thrusted over the Krol limestone and infra-krol rock in the shivalik range [31].

Experimental technique

The collected samples were analyzed using Gamma Ray Spectrometry manufactured by ATOMTEX (Belarus) is installed at Nodal Radon/Thoron Calibration Centre, HNB Garhwal University, SRT Campus, Tehri Garhwal. The Spectroscopic unit consists of NaI(Tl) Gamma radiation scintillating detector having 63 mm × 63 mm detector size with a multi-channel analyzer. The software used for analysis of the samples was AT1315 which work in three steps i.e. acquires data, analyze and display. The detector has 1024 channels having 3 keV energy per channel. The energy per peak were calibrated using Cs-137 as a reference source. For the analysis of radium, thorium and potassium, the system was calibrated for a particular energy peaks for each element. The radium content was calculated by the measurement of count rate of gamma lines for Bismuth-214 with an energy of 1764 keV. The thorium content was calculated from the count rate of thalium-208 with an energy peak of 2620 keV. While, the potassium content was calculated by identifying the peak energy of 1460 keV.

Sample preparation

The present study was conducted with a sampling dimensions of 20 Square kilometers in the Maldevta region located in the Doon valley which fall over the Main Boundary Thrust region. A prior-survey was conducted with the help of Gamma survey meter in which the sample size chosen was 100. Later, 25 samples were chosen according to the population density and its geology and variability of soil and rock type etc. Thereafter, the samples were taken from the sampling site at an approximate depth of 25–30 cm with removal of the top surface.
soil which may get transferred from some other place by human activity. The vegetation and organic material are removed from the collected samples for precise measurement of radionuclide content. These samples were then crushed into powder form and dried in an electric oven up to a temperature of 100 °C for more than 24 h. In order to obtain a fine sample, these dried samples were sieved with a sieve size of 150 micron. For uniqueness, all these dried samples were evenly seal packed in Marinelli beaker with each sample carrying 250 gm of weight and are kept for minimum 28 days to establish secular equilibrium between Ra-226, Th-232 and K-40 and their daughter products.
Fig. 2  Spatial distribution graph for radium, thorium and potassium in the Maldevta Region of Doon Valley
Fig. 3  Spatial distribution graph for radium, thorium and potassium in the Rajpur Region of Doon Valley
Calculation of annual doses received and health hazard indices Radium equivalent activity \((Raeq)\)

The naturally present radionuclides (uranium-226, thorium-232 & potassium-40) are not homogenously distributed in the soil and rocks. Therefore, a common radiological term was assumed for the representation of the activity level which was known as radium equivalent activity concentration \((Raeq)\) [32]. The activity was calculated by using the following formula [1] given in Eq. 1 as shown below:

\[
Ra_{eq} = C_{Ra} + 1.42 C_{Th} + 0.077 C_{K}
\]  
(1)

where \(C_{Ra}\), \(C_{Th}\) and \(C_{K}\) represents the activity concentration of radium, thorium and potassium respectively in the samples. The radium equivalent concentration was measured in Bq Kg\(^{-1}\).

Assessment of radiological health hazards

It is essential to study the doses received from gamma radiation to the inhabitants of the study region and the measurement of following parameters are very significant for risk assessment point of view [33, 34].

**External and internal health effects \((H_{ex} \& H_{in})\)**

The external health hazard index was calculated for the assessment of the gamma radiation effect [35]. The prime objective for calculating the index was to limitize the radiation doses under 1 mSv y\(^{-1}\) [36]. While, the inhalation of alpha particles emitted from radon, thoron and their progeny elements results in the calculation of internal health hazard index [37]. These indexes were calculated by Eq. 2 and 3:

\[
H_{ex} = \left(\frac{C_{Ra}}{370}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_{K}}{4810}\right)
\]  
(2)

\[
H_{in} = \left(\frac{C_{Ra}}{185}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_{K}}{4810}\right)
\]  
(3)

**Absorbed dose \((AD)\)**

The absorbed dose rate is the total received amount of dose in the outdoor environment due to gamma radiation in the air at a height of 1 m above the soil surface for the uniformity in distribution of Ra-226, Th-232 & K-40 [1]. Equation 4 calculates the absorbed dose rate:

\[
AD \ (\mu Gy \ h^{-1}) = 0.462 C_{U} + 0.604 C_{Th} + 0.0417 C_{K}
\]  
(4)

where, \(C_{U}\), \(C_{Th}\) and \(C_{K}\) are the content of uranium, thorium and potassium respectively. Here, it is noticeable that 98% of the gamma dose rate of uranium series is carried from radium sub-series, therefore any imbalance will not affect the concentration [38].

**Annual effective dose \((E_{in}, E_{out})\)**

This effective dose is the resultant of the absorbed dose and is calculated for indoor and outdoor according to their respective occupancies which are 80% and 20% respectively. Equation 5 and 6 evaluates the annual effective doses separately for indoor and outdoor environment [1]:

\[
E_{in}(mSv) = AD \ (\mu Gy \ h^{-1}) \times 8760 \times 0.7 \ (Sv \ Gy^{-1}) \times 0.8 \times 10^{-6}
\]  
(5)

\[
E_{out}(mSv) = AD \ (\mu Gy \ h^{-1}) \times 8760 \times 0.7 \ (Sv \ Gy^{-1}) \times 0.2 \times 10^{-6}
\]  
(6)

Here, AD is the absorbed dose rate, 8760 is annual time period (in hours), 0.8 and 0.2 is the indoor and outdoor occupancy factor respectively and 0.7 Sv Gy\(^{-1}\) is the conversion factor which converts the absorbed dose rate into human effective dose equivalent [2].

**Gamma radiation index \((\gamma_{in})\)**

Gamma radiation index is the indexing for radiation hazard calculated from the gamma doses by the below given formula [39] which was firstly calculated by [40]:

\[
\gamma_{in} = (C_{Ra}/300) + (C_{Th}/200) + (C_{K}/3000)
\]  
(7)

**Excess lifetime cancer risk \((ELCR)\)**

With the estimation of annual effective dose, one of the radiological parameter known as Excess lifetime cancer risk was also evaluated and the value for ELCR was calculated from the Eq. 8:

\[
ELCR = E \times LD \times RF
\]  
(8)

In this equation, \(E\) denotes the annual effective dose rate, LD is the Life Duration or Life expectancy which is 69.27 years (http://niti.gov.in) whereas WHO has worldwide recommended 69.1 for males and 73.8 years for females [41], RF is the risk factor which is 0.06 Sv y\(^{-1}\) [42, 43].

**Spatial distribution**

As the dataset is located pointwise on the map of District Dehradun, therefore the neighboring values were determined using inverse distance weightage approximation. The spatial...
distribution curves were plotted in QGIS 3.4.4 MADEIRA LTR software which denotes the colour coded contouring intervals. This method does not provide the actual values on neighboring locations but gives a general idea or an approximate value of the locations from where the samples were not taken.

Results and discussion

The observed natural radionuclides (Ra-226, Th-232 & K-40) and the radium equivalent content in the Rajpur and Maldevta region are tabulated in Table 1. The values for Ra-226, Th-232 & K-40 was found to vary from 47 Bq Kg$^{-1}$ to 435 Bq Kg$^{-1}$, 45 Bq Kg$^{-1}$ to 118 Bq Kg$^{-1}$ and 320 Bq Kg$^{-1}$ to 1498 Bq Kg$^{-1}$ with and average value of 93.7 Bq Kg$^{-1}$, 81.8 Bq Kg$^{-1}$ and 747 Bq Kg$^{-1}$ respectively. The calculated value for the radium equivalent was found to vary from 190.7 Bq Kg$^{-1}$ to 558.7 Bq Kg$^{-1}$ with an average value of 268.2 Bq Kg$^{-1}$.

Table 1

| Sr. No | Sampling Code | Ra (Bq.m$^{-3}$) | Th (Bq.m$^{-3}$) | K (Bq.m$^{-3}$) | Raeq (Bq.m$^{-3}$) |
|-------|---------------|-----------------|-----------------|----------------|-------------------|
| 1     | R1            | 57 ± 12         | 71 ± 12         | 971 ± 194      | 233.3             |
| 2     | R2            | 100 ± 15        | 69 ± 13         | 1011 ± 204     | 276.5             |
| 3     | R3            | 51 ± 11         | 65 ± 12         | 1013 ± 194     | 222.0             |
| 4     | R4            | 70 ± 13         | 76 ± 13         | 662 ± 175      | 229.7             |
| 5     | R5            | 120 ± 19        | 80 ± 16         | 877 ± 220      | 301.9             |
| 6     | R6            | 80 ± 14         | 118 ± 17        | 1397 ± 243     | 356.3             |
| 7     | R7            | 50 ± 12         | 75 ± 14         | 435 ± 49       | 190.7             |
| 8     | R8            | 67 ± 12         | 94 ± 14         | 834 ± 185      | 265.6             |
| 9     | R9            | 54 ± 11         | 83 ± 13         | 564 ± 155      | 216.1             |
| 10    | R10           | 69 ± 13         | 102 ± 15        | 587 ± 166      | 260.1             |
| 11    | R11           | 68 ± 13         | 99 ± 15         | 1498 ± 244     | 324.9             |
| 12    | R12           | 56 ± 12         | 108 ± 16        | 1428 ± 233     | 320.4             |
| 13    | R13           | 88 ± 15         | 87 ± 15         | 1292 ± 237     | 311.9             |
| 14    | R14           | 59 ± 12         | 98 ± 14         | 384 ± 158      | 228.7             |
| 15    | R15           | 72 ± 13         | 86 ± 14         | 672 ± 167      | 246.7             |
| 16    | R16           | 91 ± 13         | 101 ± 15        | 942 ± 190      | 308.0             |
| 17    | R17           | 76 ± 12         | 89 ± 14         | 761 ± 182      | 261.9             |
| 18    | R18           | 67 ± 12         | 86 ± 14         | 756 ± 176      | 248.2             |
| 19    | M1            | 106 ± 16        | 86 ± 16         | 947 ± 197      | 301.9             |
| 20    | M2            | 120 ± 19        | 79 ± 17         | 894 ± 201      | 301.8             |
| 21    | M3            | 435 ± 49        | 45 ± 17         | 320 ± 281      | 524.0             |
| 22    | M4            | 442 ± 50        | 51 ± 17         | 568 ± 283      | 558.7             |
| 23    | M5            | 130 ± 22        | 73 ± 14         | 547 ± 156      | 276.5             |
| 24    | M6            | 68 ± 11         | 80 ± 12         | 647 ± 120      | 232.2             |
| 25    | M7            | 82 ± 12         | 77 ± 10         | 746 ± 168      | 249.6             |
| 26    | M8            | 104 ± 16        | 81 ± 11         | 647 ± 164      | 269.6             |
| 27    | M9            | 86 ± 10         | 91 ± 13         | 546 ± 134      | 258.2             |
| 28    | M10           | 101 ± 16        | 84 ± 11         | 679 ± 158      | 273.4             |
| 29    | M11           | 86 ± 12         | 72 ± 13         | 674 ± 161      | 240.9             |
| 30    | M12           | 66 ± 11         | 79 ± 13         | 582 ± 152      | 223.8             |
| 31    | M13           | 58 ± 10         | 81 ± 13         | 670 ± 152      | 225.4             |
| 32    | M14           | 70 ± 13         | 84 ± 13         | 510 ± 143      | 229.4             |
| 33    | M15           | 96 ± 15         | 67 ± 14         | 727 ± 166      | 247.8             |
| 34    | M16           | 55 ± 12         | 81 ± 14         | 643 ± 154      | 220.3             |
| 35    | M17           | 89 ± 16         | 84 ± 13         | 629 ± 156      | 257.6             |
| 36    | M18           | 91 ± 15         | 101 ± 16        | 567 ± 143      | 279.1             |
| 37    | M19           | 81 ± 15         | 67 ± 13         | 560 ± 142      | 219.9             |
| 38    | M20           | 56 ± 10         | 73 ± 12         | 523 ± 130      | 200.7             |
| 39    | M21           | 61 ± 11         | 83 ± 14         | 761 ± 161      | 238.3             |
| 40    | M22           | 81 ± 13         | 80 ± 14         | 544 ± 152      | 237.3             |
| 41    | M23           | 54 ± 10         | 71 ± 13         | 643 ± 146      | 205.0             |
| 42    | M24           | 47 ± 9          | 82 ± 14         | 870 ± 161      | 231.3             |
| 43    | M25           | 68 ± 13         | 80 ± 14         | 593 ± 164      | 228.1             |

In the Rajpur region, the observed radium content was higher than the recommended level [1] but it was lower than that in the Maldevta region because of the uranium mineralization in the Maldevta region. While, thorium and potassium content in the Rajpur region was higher than that of the Maldevta region. The Rajpur region has a decent exposure of the MBT region which is composed of shell limestone and...
interbedded sandstone and siltstone while the Mussoorie and Sahastradhara shows a significant concentration of uranium in it due to the confirmed presence of phosphorite, chert and carbonaceous shale horizons. Therefore the radium content in the Maldevta region was found higher than the Rajpur region.

Frequency distribution graphs of radium, thorium, potassium and radium equivalent content are plotted in Origin 17 software. In Fig. 4, first graph was plotted for the radium content which tells us that 76% of the samples fall in 50–100 Bq Kg\(^{-1}\) category which was little higher than the world average radium content while 5% of the samples fall in the range of 400–450 Bq Kg\(^{-1}\) which was very high compared to the rest of the samples. The second graph was for thorium content which show that 42% of the samples fall in the category of 80–90 Bq Kg\(^{-1}\) which was again higher than the world average thorium content. Third graph was for potassium content which tells us that 2.33% of the samples fall in 200–250 Bq Kg\(^{-1}\) category which was again very high compared to the rest of the samples. The fourth graph was for radium equivalent content which shows that 41.9% of the samples fall in the category of 200–300 Bq Kg\(^{-1}\) which was again very high compared to the rest of the samples.

| Radionuclide content             | Min. value | Max. value | Average value | SD   | World average |
|----------------------------------|------------|------------|---------------|------|---------------|
| Radium-226 (Bq Kg\(^{-1}\))     | 47 ± 9     | 442 ± 50   | 109.3         | 101.3| 35            |
| Thorium-232 (Bq Kg\(^{-1}\))    | 45 ± 17    | 101 ± 16   | 77.2          | 11.4 | 30            |
| Potassium-40 (Bq Kg\(^{-1}\))   | 320 ± 281  | 947 ± 197  | 641.5         | 134.0| 400           |
| Radium Equivalent (Bq Kg\(^{-1}\)) | 200.7      | 558.7      | 269.2         | 86.2 | 370           |

Fig. 4 Frequency distribution curve for radium, thorium, potassium and radium equivalent
potassium content, which shows that 65% of the collected samples were slightly above the world average value [1].

Table 3 describes the various health hazard indices and the doses received due to the presence of natural radionuclides in the samples. The external and internal health hazard index were found to vary from 0.54 to 1.51 with an average value of 0.7 ± 0.23 and 0.69–2.70 with an average value of 1 ± 0.5 respectively. 30% of the total samples were found higher than the recommended limit which was less than 1, but the average value falls below the limit. The total absorbed doses were found to vary from 93 to 259.9 nGy h\(^{-1}\) with a mean value of 112.5 ± 39.9 nGy h\(^{-1}\) and it was found to be much higher than the world average which was 59 nGy h\(^{-1}\). The observed annual effective doses received (indoor and outdoor) were found to be much more than the recommended level which was 0.41 mSv y\(^{-1}\) for the indoor and 0.07 mSv y\(^{-1}\) for the outdoor [36]. The effective dose for the indoor environment were found to vary from 0.46 to 1.27 mSv y\(^{-1}\) with an average value of 0.61 ± 0.19 mSv y\(^{-1}\). Whereas, effective dose for outdoor were found to vary from 0.11 to 0.32 mSv y\(^{-1}\) with an average value of 0.15 ± 0.04 mSv y\(^{-1}\). The amount of gamma radiation received were calculated from the value of $\gamma$–index which was found to vary from 0.73 to 1.92 with a mean value of 0.96 ± 0.28. The recommendation limit for the gamma index was below 1 (< 1) [1]. The value for ELCR (× 10\(^{-3}\)) varies from 0.48 to 1.34 with an average value of 0.65. The value of ELCR was found to be much higher than the world average value which was 0.29 but it was found less than the recommended limit i.e. 1.45 [48].

The Frequency distribution curve for Health Hazard Index (Fig. 5) was shown separately for external and internal effects. The graph concludes that the most of the samples (around 50%) are below the recommendation limit i.e. < 1 [1]. Figure 6 shows the absorbed dose rate for the sampling site and it was found that 53.5% of samples fall in the category (100–120 nGy h\(^{-1}\)) where the average value falls which conludes that lithology of most of the sampling point was very similar to each other. The graph concludes that all the samples were above the world average value i.e. 59 nGy h\(^{-1}\) while very few samples were above the average sampling value which is 112 nGy h\(^{-1}\).
Figure 7 illustrates the Annual effective dose for the indoor and outdoor environment. The graph shows the variation of effective doses and it can be concluded that the maximum doses are received in the indoor environment. Most of the samples have value very close to the global mean value which was 0.41 and 0.07 for indoor and outdoor environment respectively. Gamma index (Fig. 8) illustrates that most of the samples were below the recommendation limit. While, Fig. 9 denotes bar graph representation for ELCR which concludes that all the values are higher than the world mean value but are below the recommendation limit.

The observed results have also been compared with the previous studies carried out in various parts of India and tabulated in Table 4. The higher potassium content in Northern Rajasthan and Haryana [15, 48] was due to the vast usage of potassium containing fertilizers in agriculture. The study carried out in Himachal Pradesh concludes with higher radium content in it [16]. This was because the study was simulated in the Shivalik region and these hills are well known as the transition zones or thrust zones having higher radionuclide content in it. The study in Orissa results in higher thorium content as the study was précised to the Chattarpur coast which has monazite type of sand which is prominently known for its high thorium content [18]. Previous studies in various parts/districts of Uttarakhand are very much comparable to the present study except the values of radium as the existing study is located on the thrust zone (Main Boundary Thrust) and these zones are identified as the highly mineralized zones.

Conclusions

The present study concludes that the natural background radionuclide content i.e. Ra-226, Th-232 & K-40 in the Maldevta region was 109 ± 101 Bq Kg⁻¹, 77 ± 11.4 Bq Kg⁻¹ and 641 ± 134 Bq Kg⁻¹ respectively which was much higher than the global average values. This was because of some prominent regions in which first is that the sampling area falls in the Main Boundary Thrust region which shows a typical geological formation. Secondly the region has high level of phosphorite deposits which are generally known for their higher uranium radioactivity content. The results of present study are very much comparable to the results of Rajpur region due to the high radium, thorium and potassium content in it. Spatial graph shows the distribution of radionuclide in the study area and gives a brief idea about the variation of geology near to the MBT region. Due to higher radionuclide content, there is higher risk for the Excess lifetime cancer risk for the inhabitants. Therefore, the study region is sensitive from health point of view. The average values for the doses received in the
study area were much higher than the global average value whereas these values are below the recommended limits suggested by various health protection agencies.

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**Table 4** Comparison of present study with other studies carried out in India

| State of India, Region | Ra-226 (Bq Kg⁻¹) | Th-232 (Bq Kg⁻¹) | K-40 (Bq Kg⁻¹) | Ra eq (Bq Kg⁻¹) |
|------------------------|-----------------|-----------------|----------------|----------------|
| Rajasthan, Marwar [48]  | 24              | 55              | 549            | 141            |
| Rajasthan, Northern [49]| 52              | 19              | 1627           | 205            |
| Himachal Pradesh [16]  | 679             | 65              | 777            | -              |
| Haryana [15]           | 52              | 187             | 1332           | -              |
| Uttarakhand, Ukhimath [17]| 80.5           | 118.9           | 341            | 276            |
| Uttarakhand, Purola [50]| 31              | 30              | 583            | 115            |
| Uttarakhand, MCT region [51]| 20             | 26              | 329            | 86             |
| Uttarakhand, Bageshwar [52]| 36             | 50              | 1595           | 228            |
| Uttarakhand, Uttarkashi, Chamoli, Tehri, Rudraprayag [19]| 64 | 69 | 792 | - |
| Karnataka [53]         | 12.6            | 40              | 711            | -              |
| Tamil Nadu [54]        | 12.5            | 17.4            | 267            | 57             |
| Orissa, Chattapur Coast [18]| 136            | 790             | 383            | 1295           |
| Doon Valley [Present Study] | 109.3           | 77.3           | 641.5          | 269            |

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