Assessment of natural radioactivity in soil collected from Jaduguda U-mines area East Singhbhum shear zone, Jharkhand India and radiological implications

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INTRODUCTION

Naturally occurring radionuclides of terrestrial origin are present in the earth’s crust since its origin. Radioactive toxic elements uranium, thorium and potassium are found in traces in almost all types of rocks, sands and waters. Due to its property to get dissolved in aqueous solution in hexavalent (U⁶⁺) form and to precipitate as a discrete mineral in tetravalent (U⁴⁺) form, uranium forms deposits in the earth’s crust where the geological conditions become favorable. Human beings are exposed to ionizing radiation from natural sources due to the occurrence of natural radioactive elements in solids, rocks, sand, soil etc. to the cosmic rays entering the earth’s atmosphere from outer space and to the internal exposure from radioactive elements through food, water and air. Natural radioactivity is wide spread in the earth’s environment and it exists in various geological formations like soils, rocks, water and sand etc. (UNSCEAR, 1993; Aly Abdo et al., 1999). Radium and its ultimate precursor uranium in the ground are the source of radon an α-radioactive inert gas. As an inert gas and having sufficiently long lifetime (3.8 days) it can move freely through the materials like soil, sand, rock etc. Short lived radon progenies have been established as causative agents of lung cancer (UNSCEAR, 1993).

Distribution of naturally occurring radionuclides mainly ²³⁸U, ²³²Th and ⁴⁰K and other radioactive elements depends on the distribution of rocks from which they originate and on the processes through which they are concentrated. Jharkhand state of India is rich in minerals and is called the store house of minerals. In addition to uranium deposits at Jaduguda, there are huge deposits of bauxite, mica and coal along with iron, copper, chromites, tungsten, lime stone, feldspar and quartz etc. The measurement of activities of naturally occurring radio nuclides ²³⁸U, ²³²Th and ⁴⁰K is important for the estimation of radiation risk and has been the subject of interest of research scientists all over the world. In the present study natural radio nuclides (²³⁸U, ²³²Th and ⁴⁰K) concentration in soil samples collected from some areas around of the East Singhbhum shear zone and U-mining area of Jharkhand state of India are measured for the estimation of effective radiation dose to assess the radiation risk to the inhabitants.

MATERIALS AND METHODS

All soil samples collected from some areas around the East Singhbhum shear zone and U-mining area of Jharkhand state were dried for 24 h in an air-circulation oven at 110 °C to ensure that moisture is completely removed. All soil samples were packed and sealed in an impermeable
airtight PVC container to prevent the escape of radiogenic gases radon (\(^{222}\text{Rn}\)) and thoron (\(^{220}\text{Rn}\)). About 300g sample of each material was used for measurements. Before measurements, the containers were kept sealed for about 4 weeks in order to reach equilibrium of the \(^{238}\text{U}\) and \(^{232}\text{Th}\) and their respective progenies. After attainment of secular equilibrium between \(^{238}\text{U}\) and \(^{232}\text{Th}\) and their decay products, the samples were subjected to high resolution gamma spectroscopic analysis.

Measurements were carried out at Inter-University Accelerator Centre, New Delhi with a coaxial n-type HPGe detector (EG&G, ORTEC, Oak Ridge, USA). The detector having a resolution of 2.0 keV at 1332 keV and a relative efficiency of 20% was placed in 4” shield of lead bricks on all sides to reduce the background radiation from building materials and cosmic rays. The detector was coupled to a PC based 4K multi channel analyzer and an ADC for data acquisition.

The calibration of the low background counting system was done with a secondary standard which was calibrated with the primary standard (RGU-1) obtained from the International Atomic Energy Agency (IAEA). The efficiency for the system was determined using secondary standard source of uranium ore in the same geometry as available for the sample counting. The samples were counted for a period of 72000 seconds for activity measurements. The activity concentration of \(^{40}\text{K}\) \((C_k)\) was measured directly by its own gamma ray of 1461 keV. As \(^{238}\text{U}\) and \(^{232}\text{Th}\) are not directly gamma emitters, their activity concentrations \((C_U\) and \(C_{Th}\)) were measured through gamma rays of their decay products. Decay products taken for \(^{238}\text{U}\) were \(^{214}\text{Pb}\): 295 and 352 keV and \(^{214}\text{Bi}\): 609,1120 and 1764 keV whereas for \(^{232}\text{Th}\) were \(^{228}\text{Ac}\) : 338, 463, 911 and 968 keV, \(^{212}\text{Bi}\) : 727 keV, \(^{212}\text{Pb}\) : 238 keV and \(^{234}\text{Pa}\) : 1001 keV gamma ray by assuming the decay series to be in equilibrium (Firestone and Shirley, 1998). To estimate the activity concentrations of \(^{238}\text{U}\) and \(^{232}\text{Th}\) weighted averages of several decay products were used. The spectra were analyzed using the locally developed software “CANDLE (Collection and Analysis of Nuclear Data using Linux Network)”.

Respective count rates after subtracting the background counts of the spectrum obtained for the same counting time were used to calculate the net count rate under the most prominent photo peaks of radium and thorium daughters. Then the activity of the radionuclide was calculated from the background subtracted area of prominent gamma ray energies. Gamma ray spectra of one typical soil sample is shown in Fig. 1. The concentration of uranium, thorium and potassium was calculated using the following equation (Mahur et al., 2008).

\[
Activity \ (Bq.kg^{-1}) = \frac{(S \pm \sigma) \times 100 \times 1000 \times 100}{E \times W \times A}
\]  

(1)

Where S is the net counts/sec (cps) under the photo peak of interest, \(\sigma\) the standard deviation of S, \(E\) the counting efficiency (%), \(A\) the gamma abundance or branching intensity (%) of the radionuclide and \(W\) is the mass of the sample (Kg).

As the soil is the basic ingredient used in construction materials in India, estimation of the radiation risk to the population is quite important and can be computed from the activities of the radio-nuclides present in these samples.
Estimation of dose rate

Outdoor air gamma absorbed dose rate \( D \) in nGy h\(^{-1}\) due to terrestrial gamma rays at 1m above the ground surface can be computed from the specific activities, \( C_U \), \( C_{Th} \), and \( C_K \) of \(^{238}\text{U} / ^{226}\text{Ra} \), \(^{232}\text{Th} \) and \(^{40}\text{K} \) in Bq kg\(^{-1}\), respectively by Monte Carlo method (UNSCEAR, 2000):

\[
D \text{ (nGy h}^{-1} \text{)} = 0.462C_U + 0.604C_{Th} + 0.0417C_K
\]

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose, \( 0.7 \text{ Sv Gy}^{-1} \) was used for the conversion coefficient from absorbed dose in air to effective dose received by adults, outdoor occupancy factor of 0.2 proposed by UNSCEAR, 2000 were used. The effective dose rate \( E \) in units of mSv y\(^{-1}\) was calculated by the following formulae:

\[
\text{Indoor effective dose } E \text{ (mSv y}^{-1} \text{)} = D \text{ (nGy h}^{-1} \text{)} \times 8760 \times 0.8 \times 0.7 \text{ Sv Gy}^{-1} \times 10^{-6}
\]

\[
\text{Outdoor effective dose } E \text{ (mSv y}^{-1} \text{)} = D \text{ (nGy h}^{-1} \text{)} \times 8760 \times 0.2 \times 0.7 \text{ Sv Gy}^{-1} \times 10^{-6}
\]

The distribution of \(^{238}\text{U} / ^{226}\text{Ra} \), \(^{232}\text{Th} \) and \(^{40}\text{K} \) in soil samples is not uniform. Uniformity with respect to exposure to radiation can be defined in term of radium equivalent activity (Ra\(_{eq}\)) in Bq kg\(^{-1}\) to compare the specific activity of materials containing different amounts of \(^{226}\text{Ra} \), \(^{232}\text{Th} \) and \(^{40}\text{K} \). It can be calculated from the following relation (Yu et al., 1992; Hayambu et al., 1995):

\[
Ra_{eq} = C_U + 1.43C_{Th} + 0.07C_K
\]

It has been assumed here that 370 Bq kg\(^{-1}\) of \(^{238}\text{U} \) or 259 Bq kg\(^{-1}\) of \(^{232}\text{Th} \) or 4810 Bq kg\(^{-1}\) of \(^{40}\text{K} \) produce the same gamma dose rate.

Beretka and Mathew (1985) defined two other indices that represent external and internal radiation hazards. The external hazard index is obtained from Ra\(_{eq}\) expression through the supposition that its allowed maximum value (equal to unity) corresponds to the upper limit of Ra\(_{eq}\) (370 Bq kg\(^{-1}\)). The external hazard index \((H_{ex})\) can then be defined as:

\[
H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \leq 1
\]

Internal exposure to \(^{222}\text{Rn} \) and its radioactive progeny is controlled by the internal hazard index \((H_{in})\) as given below (Cotton, 1990).

\[
H_{in} = C_U/185 + C_{Th}/259 + C_K/4810 \leq 1
\]

This index value must be less than unity in order to keep the radiation hazard to be insignificant.

Knowledge of radio nuclides distribution and radiation levels in the environment is important for assessing the effects of radiation exposure due to both terrestrial and extraterrestrial sources.

RESULTS AND CONCLUSIONS

Natural radio nuclides \((^{238}\text{U}, ^{232}\text{Th} \text{ and } ^{40}\text{K}) \) activity concentration from the soil samples are presented in Table 1. Radium equivalent, absorbed gamma dose rate, annual effective dose rate and external hazard index for the soil samples are given in Table 2. There are vide variations in the activity concentrations and are found to vary from 6.1 ± 0.2 to 826.3 ± 8.5 Bq kg\(^{-1}\) for \(^{238}\text{U} \), from 8.7 ± 0.3 to 236.7 ± 3.2 Bq kg\(^{-1}\) for \(^{232}\text{Th} \) and BDL to 1399.1 ± 14.3 Bq kg\(^{-1}\) for \(^{40}\text{K} \). The sample JS-1 from near the Jaduguda U mine has the highest value of uranium activity with small value for thorium activity which is expected in uraniferous regions. Variations in natural radioactivity levels in the soil samples collected from different sampling sites are due to variation of concentrations of these elements in geological formations. From the activity concentration of \(^{238}\text{U} \), \(^{232}\text{Th} \) and \(^{40}\text{K} \) in these soil samples the radium equivalent activity (Ra\(_{eq}\)) due to the presence of radio nuclides is calculated and varies from 34.0 to 922.5 Bq kg\(^{-1}\) with an average value of 256.0 Bq kg\(^{-1}\). Total absorbed gamma dose rates in the surroundings air are found to vary from
15.2 to 425.9 nGy h\(^{-1}\) with an average value of 120.6 nGy h\(^{-1}\). Fig. 2 shows a plot of the variation of \(^{238}\text{U},^{232}\text{Th},^{40}\text{K}\) and absorbed dose rate in these soil samples.

Indoor and outdoor annual effective dose rate from these soil samples are determined from 0.7 to 2.08 mSv y\(^{-1}\) and 0.02 to 0.52 mSv y\(^{-1}\) respectively. External hazard index, \(H_{\text{ex}}\) for the soil samples studied in this work range from 0.09 to 2.46 with mean a value of 0.70. The internal exposure to \(^{222}\text{Rn}\) and its radioactive progeny is controlled by the internal hazard index \(H_{\text{in}}\). Computed values of \(H_{\text{in}}\) vary from 0.15 to 4.76 with an average value of 0.96. Since most of these values of \(H_{\text{ex}}\) are less than unity except two soil samples JS-1 from near the Jaduguda uranium mines and JS-19 showing higher values than unity, the use of soil from this region can be used as construction material without posing significant radiological threat to population.

**ACKNOWLEDGMENTS**

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**REFERENCES:**


Fig. 1. Spectra of the soil samples from East Singhbhum shear zone U-mining area of Jharkhand state of India. The legends are: Ra-226 (△), Pb-214 (●), Bi-214 (◆).

Fig. 2. Bar diagram showing activity concentration of $^{238}$U, $^{232}$Th, and $^{40}$K and absorbed gamma dose rate in different soil samples.
Table-1
Natural radioactivity in soil samples collected from around the East Singhbhum shear zone and U-mining area of Jharkhand state

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Location of Samples</th>
<th>$^{238}$U ( Bq Kg$^{-1}$)</th>
<th>$^{232}$Th (Bq Kg$^{-1}$)</th>
<th>$^{40}$K (Bq Kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JS-1</td>
<td>Near Jaduguda U-mine</td>
<td>826.3 ± 8.5</td>
<td>53.0 ± 2.2</td>
<td>291.5 ± 4.4</td>
</tr>
<tr>
<td>JS-7</td>
<td>Gamaharia main market</td>
<td>40.9 ± 1.6</td>
<td>17.9 ± 1.6</td>
<td>349.5 ± 5.0</td>
</tr>
<tr>
<td>JS-12</td>
<td>Tata Swarn Rakha River</td>
<td>6.1 ± 0.2</td>
<td>24.1 ± 0.8</td>
<td>401.3 ± 5.4</td>
</tr>
<tr>
<td>JS-13</td>
<td>Chanduka Mines</td>
<td>21.6 ± 0.4</td>
<td>8.7 ± 0.3</td>
<td>BDL</td>
</tr>
<tr>
<td>JS-17</td>
<td>Tata outer-I</td>
<td>61.4 ± 1.1</td>
<td>130.6 ± 2.6</td>
<td>757.8 ± 10.1</td>
</tr>
<tr>
<td>JS-19</td>
<td>Tata Telco</td>
<td>273.2 ± 3.1</td>
<td>236.7 ± 3.2</td>
<td>710.7 ± 9.2</td>
</tr>
<tr>
<td>JS-21</td>
<td>B-Block Bokaro</td>
<td>61.1 ± 0.8</td>
<td>73.2 ± 1.5</td>
<td>1399.1 ± 14.3</td>
</tr>
<tr>
<td>JS-22</td>
<td>Bokaro Stone Mines</td>
<td>26.7 ± 0.6</td>
<td>19.5 ± 0.5</td>
<td>626.1 ± 7.7</td>
</tr>
<tr>
<td>JS-23</td>
<td>River Side Bokaro</td>
<td>19.8 ± 0.5</td>
<td>35.5 ± 0.9</td>
<td>901.0 ± 9.9</td>
</tr>
<tr>
<td>JS-24</td>
<td>Sector IX-D Bokaro</td>
<td>18.3 ± 0.3</td>
<td>40.1 ± 0.5</td>
<td>981.3 ± 10.9</td>
</tr>
<tr>
<td>JS-25</td>
<td>Sector IX-C Bokaro</td>
<td>12.5 ± 0.3</td>
<td>12.3 ± 0.6</td>
<td>304.4 ± 4.1</td>
</tr>
<tr>
<td>JS-26</td>
<td>Sector IX-Bokaro</td>
<td>61.2 ± 0.9</td>
<td>122.4 ± 2.1</td>
<td>941.9 ± 10.6</td>
</tr>
</tbody>
</table>

*BDL - Below Detection Limit.
Table 2

Radium equivalent activity, absorbed gamma dose rate, Indoor and Outdoor effective dose rates, external and internal hazard Index in soil samples collected from around the East Singhbhum shear zone and U-mining area of Jharkhand state, India

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Radium equivalent activity (Ra&lt;sub&gt;eq&lt;/sub&gt;) Bq kg</th>
<th>Absorbed gamma dose rate (D) nGy h&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>Indoor effective dose rate (mSv y&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Outdoor effective dose rate (mSv y&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>External Hazard Index (H&lt;sub&gt;ex&lt;/sub&gt;)</th>
<th>External Hazard Index (H&lt;sub&gt;in&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JS-1</td>
<td>922.5</td>
<td>425.9</td>
<td>2.08</td>
<td>0.52</td>
<td>2.46</td>
<td>4.76</td>
</tr>
<tr>
<td>JS-7</td>
<td>91.0</td>
<td>44.3</td>
<td>0.21</td>
<td>0.05</td>
<td>0.24</td>
<td>0.35</td>
</tr>
<tr>
<td>JS-12</td>
<td>68.7</td>
<td>34.1</td>
<td>0.17</td>
<td>0.04</td>
<td>0.18</td>
<td>0.20</td>
</tr>
<tr>
<td>JS-13</td>
<td>34.0</td>
<td>15.2</td>
<td>0.07</td>
<td>0.02</td>
<td>0.09</td>
<td>0.15</td>
</tr>
<tr>
<td>JS-17</td>
<td>301.2</td>
<td>138.8</td>
<td>0.68</td>
<td>0.17</td>
<td>0.83</td>
<td>0.99</td>
</tr>
<tr>
<td>JS-19</td>
<td>661.4</td>
<td>298.8</td>
<td>1.46</td>
<td>0.37</td>
<td>1.80</td>
<td>2.56</td>
</tr>
<tr>
<td>JS-21</td>
<td>263.7</td>
<td>130.8</td>
<td>0.64</td>
<td>0.16</td>
<td>0.74</td>
<td>0.90</td>
</tr>
<tr>
<td>JS-22</td>
<td>98.4</td>
<td>50.2</td>
<td>0.25</td>
<td>0.06</td>
<td>0.28</td>
<td>0.35</td>
</tr>
<tr>
<td>JS-23</td>
<td>133.6</td>
<td>68.2</td>
<td>0.33</td>
<td>0.08</td>
<td>0.38</td>
<td>0.44</td>
</tr>
<tr>
<td>JS-24</td>
<td>144.3</td>
<td>73.6</td>
<td>0.33</td>
<td>0.09</td>
<td>0.40</td>
<td>0.44</td>
</tr>
<tr>
<td>JS-25</td>
<td>51.4</td>
<td>25.9</td>
<td>0.13</td>
<td>0.03</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>JS-26</td>
<td>302.2</td>
<td>141.5</td>
<td>0.69</td>
<td>0.17</td>
<td>0.83</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Average Value</strong></td>
<td><strong>256.0</strong></td>
<td><strong>120.6</strong></td>
<td><strong>0.59</strong></td>
<td><strong>0.15</strong></td>
<td><strong>0.70</strong></td>
<td><strong>0.96</strong></td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td><strong>261.2</strong></td>
<td><strong>118.7</strong></td>
<td><strong>0.58</strong></td>
<td><strong>0.15</strong></td>
<td><strong>0.70</strong></td>
<td><strong>1.31</strong></td>
</tr>
<tr>
<td><strong>Rel.Std.%</strong></td>
<td><strong>102.0</strong></td>
<td><strong>98.4</strong></td>
<td><strong>98.3</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>136.1</strong></td>
</tr>
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</table>