

Spatial variability and multivariate analysis of natural radioactivity in monazite-bearing coastal soils of Odisha, India

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Supplementary Text S1. Equations used for radiological hazard assessment

The radiological hazard parameters were calculated using established formulations reported in the literature, with the dose-conversion factors, occupancy factors, and reference values adopted from relevant literature and the recommendations of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3] and the International Commission on Radiological Protection (ICRP) [39]. The equations and calculation parameters used in the present study are given below.

The radium equivalent activity (Ra_{eq}), representing the combined radiological effect of ^{238}U , ^{232}Th , and ^{40}K , is given by:

$$Ra_{eq}(\text{Bq kg}^{-1}) = C_U + 1.43 C_{Th} + 0.077 C_K \text{ ----- (S1)}$$

where C_U , C_{Th} and C_K are the activity concentrations (Bq kg^{-1}) of ^{238}U , ^{232}Th , and ^{40}K , respectively.

The absorbed gamma dose rate (D) in air at 1 m above ground level is calculated as:

$$D (\text{nGy h}^{-1}) = 0.462 C_U + 0.604 C_{Th} + 0.0417 C_K \text{ ----- (S2)}$$

The annual effective dose (AED) is estimated using:

$$\text{AED} (\text{mSv y}^{-1}) = D \times 8760 \times 0.7 \times \text{OF} \times 10^{-6} \text{ ----- (S3)}$$

where 0.7 Sv Gy^{-1} is the dose conversion factor and OF is the occupancy factor (0.2 for outdoor and 0.8 for indoor exposure).

The in situ ambient gamma dose rate measured at each sampling location was converted to annual ambient gamma dose (AMD) for spatial representation and comparison with the calculated radiological dose parameters using:

$$\text{AMD} (\text{mSv y}^{-1}) = D_{amb} \times 8760 \times 10^{-6} \text{ ----- (S4)}$$

where D_{amb} is the measured ambient gamma dose rate in nSv h^{-1} . The factor 8760 represents the number of hours in a year, and 10^{-6} converts nSv to mSv .

The annual gonadal dose equivalent (AGDE) is estimated using:

$$\text{AGDE (mSv y}^{-1}\text{)} = (3.09 C_U + 4.18 C_{Th} + 0.314 C_K) \times 10^{-3} \text{ ----- (S5)}$$

The external hazard index (H_{ex}) and internal hazard index (H_{in}) are defined as:

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \text{ ----- (S6)}$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \text{ ----- (S7)}$$

The representative gamma index (I_γ) is calculated as:

$$I_\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \text{ ----- (S8)}$$

The excess lifetime cancer risk (ELCR) is estimated using:

$$\text{ELCR} = \text{AED} \times \text{DL} \times \text{RF} \times 10^{-3} \text{ ----- (S9)}$$

where DL is the average life expectancy (70 years) and RF is the fatal cancer risk factor (0.05 Sv^{-1}), as recommended by ICRP. The factor 10^{-3} converts AED from mSv y^{-1} to Sv y^{-1}

The calculated indices were interpreted using the recommended reference values of $R_{eq} \leq 370 \text{ Bq kg}^{-1}$, $D = 49 \text{ nGy h}^{-1}$, $\text{AED} = 1 \text{ mSv y}^{-1}$, $H_{ex} \leq 1$, $H_{in} \leq 1$, and $I_\gamma \leq 1$. An AGDE value of $300 \mu\text{Sv y}^{-1}$ (0.3 mSv y^{-1}) was used as a reference value for comparison.