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Distribution pattern of the *in situ* terrestrial gamma radiation in uranium mineralized Singhbhum Shear Zone, Jharkhand and its correlation with local geology

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Terrestrial gamma radiation is one of the important radiation exposures on the Earth's surface that results primarily from the three primordial radionuclides, viz. U, Th and K. The elemental concentrations of these elements in the Earth's crust could result in the anomalous variation of the terrestrial gamma radiation in the environment. The geology of a region plays an important role in distribution of these radioactive elements. *In situ* gamma radiation measurements in the soils and adjacent rock exposures along the Singhbhum Shear Zone, Eastern India were undertaken using a portable radiation survey meter. The results showed that the area has a reasonably close concordance with the geological formations, and the observed gamma radiation levels, since both geological features and mineralogical composition have good control on the terrestrial gamma radiation in the area. Correlation between the gamma level of soils and the underlying rocks was very poor. This suggests that the soils might not have originated from underlying rocks or might have different weathering mechanisms.

Keywords: Geological controls, Singhbhum Shear Zone, soils and rocks, terrestrial gamma radiation.

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Terrestrial gamma radiation (19.6%, UNSCEAR 2000) has major contributions from the natural radionuclides mainly uranium, thorium and potassium. Average abundance of uranium and thorium in the Earth's crust are 2.8 ppm (www.world-nuclear.org) and 7.2 ppm (www.mii.org) respectively, while potassium has an average crustal abundance of 2% by mass[1]. The geology of a region plays an important role in distribution of these elements and therefore gamma intensity profiles have been used by many investigators to determine several geological characteristics (e.g., faults, shear zones, schistose rocks) and to locate ore-bodies[2–7]. Outdoor terrestrial gamma radiation generally originates from the upper 30 cm of the soil[8]. Weathering and metamorphism are important processes in modifying the redistribution of these radioactive elements[9]. Background radiation may be high in the vicinity of the uranium mineralized zones[10–12], near different deep-seated tectonic structures within the Earth's crust[13,14] and thorium rich beach sands in the world[15,16], as well as in India[17–22]. Shear zones have aerial radioactivity anomalies due to introduction of U-bearing fluid and/or relative enrichment in U by volume loss[14]. The texture imparted to the rock during shearing may also increase its permeability[13].

The Singhbhum Shear Zone (SSZ) in Jharkhand, eastern India, is one of the reasonably well-studied shear zones (Figure 1). The SSZ is also one of the richest mineralized zones in India[23,24] with economic concentration of uranium (grade of the ore 0.067%, ref. 25) and copper. This economic concentration of ^{238}U contributes significant natural radioactivity in this area[26–28]. There was no extensive survey undertaken to map the radioactivity distribution in this area. The present study describes the distribution pattern of terrestrial gamma radiation level in the area. In addition, the geological study has helped determine the anomalous radiation potential zones and its correlation with the different geological formations and the structural aspects.

The present study area comprises the central part of the Singhbhum Shear Zone or Singhbhum Copper Belt Thrust Zone and the uranium mineralization is confined within this zone[29]. This zone is ~1–10 km wide and over ~200 km long. Presence of numerous ultramafic bodies all along the southern margin and in the thrust zone itself[29] and regional gravity studies[30] indicate that SSZ is a deep-seated thrust zone. This part of the SSZ includes the Singhbhum Group (SG) of rocks in the north, the Dhanjori Group (DG) of rocks and the Singhbhum Granite in the south (SBG-III) (Figure 1)[29]. The SG of rocks consists of a monotonous sequence of pelitic schists, intercalated with micaceous quartzites and mafic to ultramafic volcanics[24,29,31]. The DG consists of quartzite and metapelite in the lower part and mafic and ultramafic tuffs with low-Al, quartz normative tholeiitic lavas[29–32]. SBG-III is granodiorite to granitic in composition[33]. The area also includes rocks, which are mylonitized due to shearing in SSZ. Uranium was primarily deposited with sediments along the northern margin of the Singhbhum Craton as leached out product of the basement Singhbhum granite complex and later remobilized and enriched to form ore bodies by hydrothermal activity[23–25]. The present study area lies in the vicinity of Jaduguda (22°39′03.82″N; 86°20′07.09″E) (Figure 1).

Measurements were conducted at various sampling locations. In total, there were 92 sampling locations comprising of 50 soil sample locations and 42 underlying rock exposures (Figure 1). The latitude and longitude for each location were determined by the Global Positioning System receiver, Garmin, GPS 12 (Garmin International, USA). All the measurements of the γ-radiation were undertaken by a portable plastic scintillator based counting system. This is a micro-R Survey Meter, Type-UR 705 and manufactured by Nucleonix Systems Private Limited, Hyderabad, India. It is designed around an integrally coupled 2.54 cm × 2.54 cm scintillator coupled to a 2.54 cm × 1.27 cm photomultiplier tube. Measurements were not undertaken during or immediately after monsoon to avoid the interference of gamma-emitting radon decay products[34]. In case of γ-measurements from rocks, the detector was placed at ~5 cm above the exposed surface, while in soils, measurements were undertaken both at ~5 cm above the ground surface and ~1 m above the surface. Each measurement was carried out for more than one minute and was repeated three times for better precision and the subsequent interpretation in terms of the ambient radiation data was accomplished.

Detailed mineralogical description of the SBG-III, SG and DG is given here. The granite comprises the following mineral assemblages: quartz + plagioclase + microcline + biotite + muscovite + opaque mineral. The massive granite and foliated granite are similar in mineralogical compositions, presence of foliation plane poses the only difference. In the present study, all schists are characterized by biotite + quartz + muscovite + opaque mineral ± garnet ± chlorite. Massive quartzites are characterized by the following mineral assemblages: quartz + white mica + biotite + opaque mineral. Massive banded rocks are composed of alternate banding of quartz layer and opaque mineral rich layer. The characteristic feature of shally quartzite is presence of high percentage of mica compared to quartzite. The characteristic mineral assemblages of this rock type are quartz + white mica + biotite + opaque mineral. Slates are composed of extremely fine grained quartz + biotite + muscovite + opaque minerals. Mylonites are very fine grains in these rocks and are composed of quartz + biotite + muscovite + opaque minerals. Though zircon and sphene are ubiquitous in almost every rock in the study area, their abundance is higher in granites compared to any other rock. Apatite, epidote and microcline are the other important accessory minerals in granite. In schists, shally quartzites and slates chlorite,

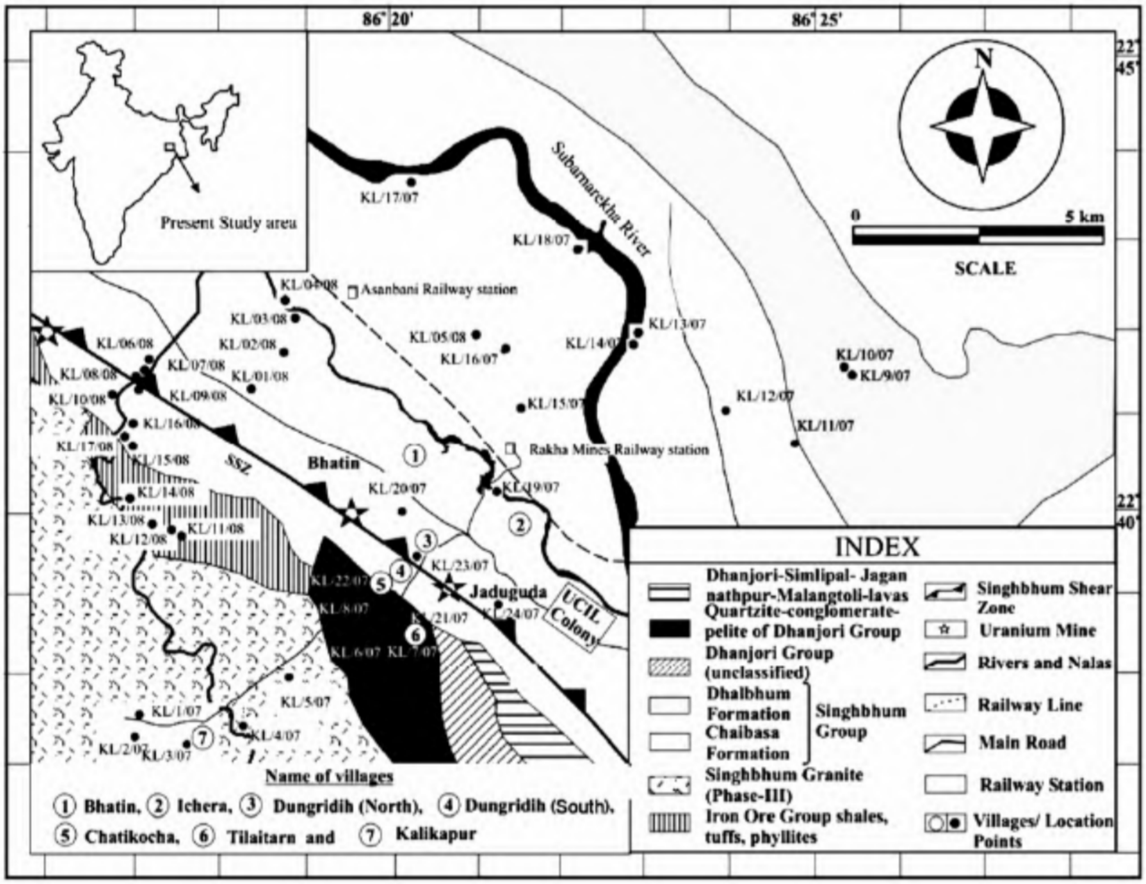

Figure 1. Geological map of the study area showing the location points of the measurements and the villages (modified after Saha[29]).

epidotes are very common. Interestingly, in schists in the north of the SSZ, aluminosilicates, viz. garnet, chlorite, sillimanite, staurolite and kyanite are developed along with negligible abundance of sphene and zircon. Near the SSZ all rock groups were metamorphosed and sheared[29]. During the field study it was observed that intensity of deformational structures of the rocks decreases away from the shear zone, which has also been documented by previous studies[35]. Since foliation plane increases porosity in the rock, these four foliated rock types are more porous than the massive variety.

Measurements of soil γ-radiation were undertaken in seven villages chosen for the present survey, viz. Bhatin, Tilaitarn, Chatikocha, Dungridih North, Dungridih South, Ichera and Kalikapur. Among the seven villages, Bhatin and Ichera overlie the Singhbhum Group comprising mica schists. Both Dungridih north and south villages are located on the mylonitic rock formation within the shear zone. Chatikocha and Tilaitarn villages overlie DG of metasedimentary rocks and Kalikapur village is located on the Singhbhum Granite.

The external γ-radiation level from 50 soil samples and 42 rock samples is summarized in Tables 1 and 2 respectively. Isorad contours along with the available geological information and detailed field survey has been plotted in Figure 2. This figure depicts the details of the *in situ* γ-ray variation of the area. With the available data, it can be inferred that the γ-radiation was anomalous in the geological formations of the area. Quartzites of SG in the north of the SSZ (Figure 1) had the lowest level of radiation with the average value of ~6 μR/h, while the DG of quartzites in south showed the average level of ~6.6 μR/h. The shear zone plays an important role on the γ-level in the study area and it was more (~12.1 μR/h) in the quartzites close to the shear zone than that of other quartzites exposed at relative distance from the SSZ. Even the less fractured banded quartzites which are close to the shear zone showed a comparative value of 11.5 μR/h. Shear zone has also increased the γ-level in the shally quartzites and the value was ~15 μR/h near the shear zone. This value was also comparatively more than the other shally quartzites exposed in the area. In mica schists, the role of the SSZ is not understood as the high abundance of K-rich muscovite and biotite in mica schists may contribute a large part of gamma radiation by K. However the observed level was low in granites though

Table 1. *In situ* gamma radiation from rocks in the Singhbhum Shear Zone area

Rock type	Location point	Gamma level (μR/h)	Average gamma level (μR/h)
Massive quartzite	KL/21/07	4.5 ± 0.7	9.1 ± 3.5
	KL/10/08	16.0 ± 2.4	
Shally quartzite	KL/10/07	6.0 ± 0.9	10.5 ± 6.3
	KL/16/08	14.9 ± 2.2	
Massive granite	KL/02/07	5.0 ± 0.8	5.7 ± 0.9
	KL/01/07	6.3 ± 0.9	
Foliated granite	KL/05/07	6.0 ± 0.9	8.7 ± 0.3
	KL/03/07	12.0 ± 1.8	
Massive banded rock	KL/23/07	11.5 ± 1.7	–
Mica schists	KL/13/07	13.0 ± 2.0	15.8 ± 3.2
	KL/17/07	21.3 ± 3.2	
Garnet–mica schist	KL/12/07	11.0 ± 1.7	14.5 ± 2.6
	KL/17/07	21.3 ± 3.2	
Chlorite–mica schist	KL/05/08	14.6 ± 2.2	16.7 ± 3.2
	KL/01/08	20.4 ± 3.1	
Mylonite	KL/18/08	16.7 ± 2.5	18.4 ± 2.3
	KL/07/08	20.0 ± 3.0	
Slate	KL/11/08	16.4 ± 2.5	17.7 ± 1.0
	KL/12/08	18.7 ± 2.8	
Mafic body	KL/06/07	10.0 ± 1.5	–
Quartz vein	KL/02/08	11.1 ± 1.7	–

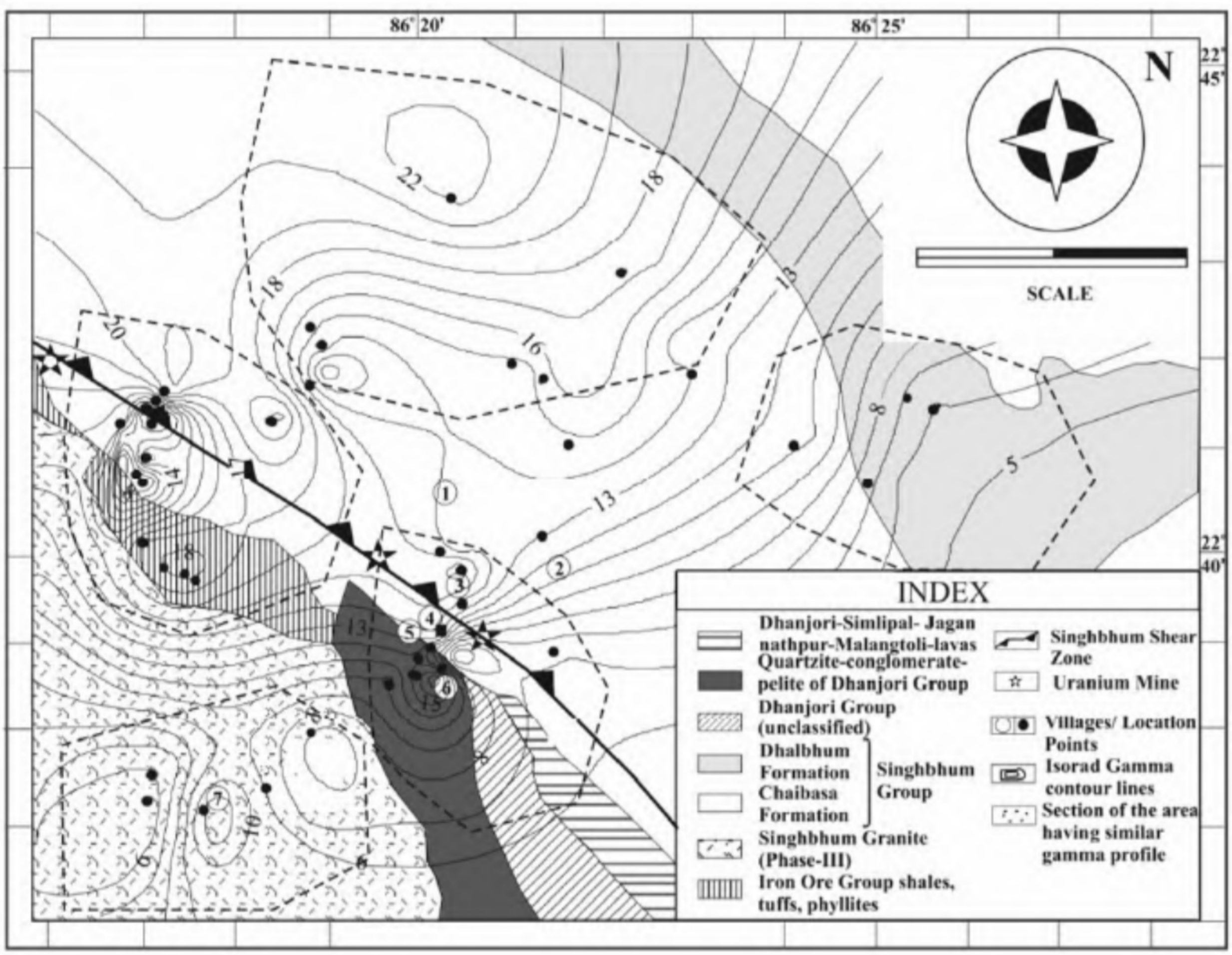

Figure 2. Isorad map of the study area for the ambient *in situ* terrestrial gamma radiation (microR/h).

they have a high proportion of zircons, sphenes and apatites. Gamma ray is also produced from the daughter products of the U and Th namely radon and thoron. Since radon and thoron are noble gases in nature, they can be exhaled into open atmosphere through porous rock. As porosity increases with the schistosity and cracks in rocks, it could be possible that low porosity in massive granites decreases the emission of these gases and finally attenuates the gamma radiation.

Table 2. *In situ* gamma radiation level from the soil samples in the Singhbhum Shear Zone area

Village	Average gamma level at ground level (μR/h)	Average gamma level at 1 m height (μR/h)
Ichera	13.5 ± 2.4	10.9 ± 2.6
Tilaitarn	10.8 ± 2.8	8.9 ± 2.9
Dungridih north	14.5 ± 2.0	12.6 ± 2.0
Dungridih south	17.1 ± 8.6	15.3 ± 6.0
Chatikocha	9.0 ± 1.1	6.6 ± 1.4
Kalikapur	13.4 ± 5.2	9.4 ± 3.4
Bhatin	11.2 ± 3.0	8.9 ± 1.9

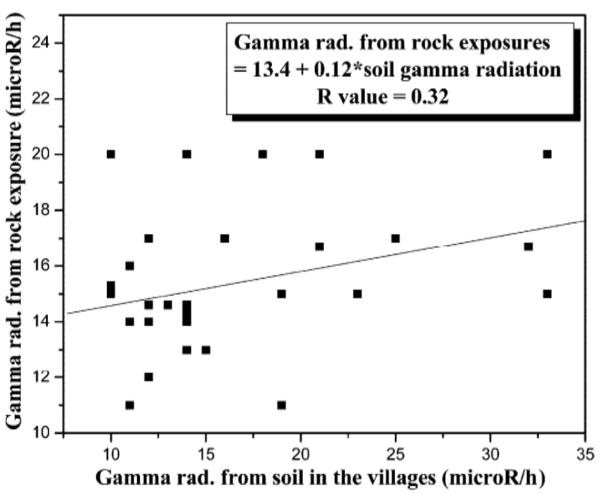

Figure 3. Correlation between gamma radiation from soil in the villages and from underlying rocks in the study area.

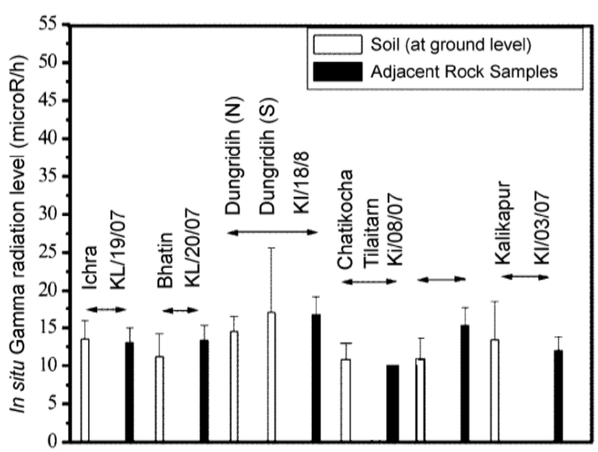

Figure 4. Comparison of the mean gamma radiation level of the soils from villages and respective rock exposures.

Results showed that the γ-radiation obtained at ground level from soils exhibit a poor correlation (correlation coefficient of + 0.32) with that of the underlying rocks (Figure 3). This suggests that soils might not have originated from their underlying rocks. This could be possible if different weathering mechanisms and subsequent transport affect the underlying rocks during the process of soil formation. The average gamma radiation level from the soils of Ichera, Kalikapur and Bhatin villages was almost identical when compared to the exposed rocks underneath. The average gamma level from the soils in Chatikocha, Tilaitarn, Dungridih north and Dungridih south villages respectively was higher than that in the rocks in the vicinity (Figure 4).

In situ measurements represented the ambient gamma radiation level in this region. The following conclusions can be drawn based on the results obtained from the present study:

- The area has a close correlation of the geological formations with the observed gamma radiation levels. Anomalous radioactivity concentration can be grouped into four sectors having nearly identical gamma radiation levels, which are from (a) NE section (5–8 μR/h), (b) NW section (16–18 μR/h), (c) SW section (6–10 μR/h) and (d) two isolated zones in the central section (15–20 μR/h). Geological map of the area is in concordance with these anomalous activity sectors. NE section can be correlated with the quartzites of the SG, while SW section coincides with the exposures within the Singhbhum Granite. In the study area, elevated radiation levels from the rocks coincide with the mica schists of the SG. The two isolated bodies of elevated radiation level in this region help in delineation of the SSZ.
- Gamma radiation is affected by the shear zone and different mineralogical compositions of the rocks exposed. Abundance of K-rich biotite and muscovite in the mica schists and slates exhibits more radiation level than K-poor quartzites and granites.
- Rock deformational structures (e.g. foliation plane, etc.) increase the intensity of gamma radiation; specially in schists and shally quartzites, the effect is intense when compared to massive quartzites. This effect can also be observed in foliated granites compared to massive granites. These structures impart porosity in rocks and therefore the extent of the radiation level might have been observed to be more in schists (mainly in northern part of the SSZ) compared to the massive rocks in south.

- The weak correlation between the gamma level of the soils with that of the underlying rocks indicate that the underlying rocks may not be source material of overlying soils. Gamma level from soils was found to be higher in the villages which are relatively close to the shear zone.

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