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Assessment of ambient gamma dose rate around a prospective uranium mining area of South India – A comparative study of dose by direct methods and soil radioactivity measurements

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ABSTRACT

Indoor and outdoor gamma dose rates were evaluated around a prospective uranium mining region – Gogi, South India through (i) direct measurements using a GM based gamma dose survey meter, (ii) integrated measurement days using $CaSO_4$:Dy based thermo luminescent dosimeters (TLDs), and (iii) analyses of 273 soil samples for ^{226}Ra, ^{232}Th, and ^{40}K activity concentration using HPGe gamma spectrometry. The geometric mean values of indoor and outdoor gamma dose rates were 104 nGy h^{-1} and 97 nGy h^{-1}, respectively with an indoor to outdoor dose ratio of 1.09. The gamma dose rates and activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K varied significantly within a small area due to the highly localized mineralization of the elements. Correlation study showed that the dose estimated from the soil radioactivity is better correlated with that measured directly using the portable survey meter, when compared to that obtained from TLDs. This study showed that in a region having localized mineralization in situ measurements using dose survey meter provide better representative values of gamma dose rates.

1. 1. Introduction

Human beings are constantly exposed to natural sources of ionizing radiations in nature. The natural background radiations have both terrestrial and extra-terrestrial origins. The extra-terrestrial radiation is largely due to cosmic rays. The worldwide average radiation dose at sea level due to cosmic rays is 31 nGy h^{-1} [17] and that for India is 32 nGy h^{-1} [13], the dose increases with the altitude. The terrestrial gamma rays are essentially derived from ^{40}K and radionuclides belonging to ^{238}U and ^{232}Th series that are present in the earth's crust. The worldwide average value for outdoor gamma absorbed dose rate in air due to terrestrial sources is 54 nGy h^{-1} and the relative contributions of ^{40}K, ^{238}U, and ^{232}Th to this dose are about 35%, 25%, and 40%, respectively [16].

The variation of terrestrial radiation is typically larger than that of cosmic rays. There are regions in the world where the outdoor terrestrial radiation exceeds substantially the average value due to the enrichment of certain radioactive minerals leading to the formation of what are known as high background areas. The presence of high background areas has been reported in several countries like China, Iran, Germany, USA, Brazil, and India [17].

Gogi – a village in Shahapur taluk in Yadgiri district of Karnataka, South India has been identified as a prospective uranium mining area. A pre-operational study to establish a baseline database on gamma radiation levels and natural radionuclide concentrations around the proposed uranium mining area is essential because such a study would help to assess the radiological impact of long term mining operations on the environment. Hence, we have undertaken pre-operational studies around the proposed mining region and in this paper we report the indoor and outdoor external gamma absorbed dose rates and activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the soils. A comparative study of in situ measurements of gamma dose rates using portable dosimeters and integrated measurements over a period of 90 days using TLDs, and their correlations with the dose estimated from the soil radioactivity is also presented and discussed.

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2. Materials and methods

2.1. Details of the study area

Gogi village (16° 43′ 28″ N, 76° 44′ 29″ E) is located in the Shahapur taluk of Yadgiri district in the north-east part of Karnataka state. The geographical area of Yadgiri district is 5234.4 km^2 with a population of ~1.2 million with an average population density of 224 per km^2. The northern part of the district represents a plateau, typical of the Deccan Trap terrain and is deeply indented with ravines. The southern part represents an undulating terrain. Different types of soil, such as deep black, medium black, shallow, and lateritic are found in the district. The deep and medium black soil practically covers the entire area, except a small portion towards the northern part of the district. Black soil is derived from the basaltic rocks and varies in colour from medium to deep black.

The weather in the region consists of three main seasons. Summer spans from late February to mid-June. It is followed by the southwest monsoon, which spans from mid June to late September and the average annual rainfall is 839 mm. It is then followed by dry winter weather until mid-January. Temperatures during the different seasons are (i) summer: 37–46 °C, (ii) monsoon: 25–37 °C, and (iii) winter: 12–32 °C. The humidity varies from 26–62% throughout the year.

Uranium mineralization in the Neoproterozoic Bhima river basin has been found at Gogi of North Karnataka, India. Mineralization at Gogi occurs within the major E-W trending Gogi-Kurlagere fault, near to its intersection with a NE-SW trending fault and is hosted by both brecciated, siliceous limestone and deformed basement rock represented by low-Ca biotite granite–granodiorite. Over 80% of the mineralization at Gogi occurs as veins, veinlets and fracture-fills, composed of coffinite, lesser pitchblende, accessory U–Ti–Si complex (only in granitoid), associated intimately with reductants like sulphides and organic matter, and also clays (illite, smectite) [15].

For in situ measurement of gamma dose rates and for soil sampling, the region was divided into 3 different zones (0–5 km Core zone, 5–15 km Buffer zone I, and 15–30 km Buffer zone II, shown in Fig. 1), with the proposed mining site (Gogi) as the center of all the zones. Sampling locations were identified in all the three zones and the latitude and longitude were noted using a Global Positioning System (GPS). A total of 39 sampling locations are identified in such a way that they are spread uniformly in all the directions in different zones so that the entire region is covered under the study.

2.2. Gamma absorbed dose measurements using portable dose survey meter

The ambient gamma absorbed dose rates were measured in all sampling locations in the three zones using GM tube based gamma dosimeter (RDS-31, Mirion, France). This device can detect gamma rays in the energy range of 40 keV to 3 MeV and the dose rate measurement range is 10 nGy h^{-1} to 0.1 Gy h^{-1}. It is factory calibrated and the calibration accuracy is ±5% with ^{137}Cs source. A total of 39 locations were monitored during this study (Fig. 1) and these locations are situated in the mainly inhabited areas. The gamma radiation levels were measured both inside and outside the dwellings at 1 m above the ground. About 25 readings were taken at different points in each location, and the geometric mean was considered as the representative value of the gamma dose rate for the location. These measurements were carried out during different seasons of the year.

2.3. Gamma absorbed dose measurements using Thermo luminescent dosimeter (TLD)

TLD is a passive device for the measurement of gamma dose and in this the dose is acquired and stored for a long period of time until the system is stimulated by heat. The advantage of this system is that since it acquires the dose continuously the variation of dose during different periods of time is averaged out. Therefore, the long-term integrated measurements of gamma dose rates are carried out using thermo luminescent dosimeters based on $CaSO_4$:Dy phosphor. The dosimeters were specially designed to measure the environmental gamma radiation by the Bhabha Atomic Research Centre (BARC), Mumbai Chougaonkar et al. [3]. The details of the preparation of the TLD dosimeters and calibration are published elsewhere by Chougaonkar et al. [3].

The TLDs were deployed inside 23 dwellings and 21 outdoor locations of three zones of the study region for a time period of 90 days. Inside the dwellings, they were installed at least 1 m away from the walls and about 3 m above the floor. In the outdoors they were installed just outside the dwelling at a similar height. After the exposure period, the exposed TLDs were retrieved and replaced by new ones and in this way the gamma dose rates were measured for one year (for 4 different quarters of a year – January to March 2012, April to June 2012, July to October 2012, and November 2012 to February 2013). The retrieved dosimeters were analyzed using the automatic reader (BARC, Mumbai) and the absorbed dose was arrived at using standardized methodology [3]. An appropriate number of TLDs were kept as control TLDs at both laboratory and field location to determine the control dose at both these locations and transit TLDs were used to determine the transit dose. At the time of installing and retrieving the TLDs, the gamma dose rates were measured using the survey meter, as detailed in the earlier section.

2.4. Soil sample collection and measurement of radionuclide activity concentrations

A total of 273 surface soil samples (from 0 to 10 cm soil profile) were collected from those 39 locations (Fig. 1) where gamma dose was measured. All the soil samples were collected from outdoor in the surrounding areas of the dwellings. The samples were processed following the standard procedure [4,5]. After processing, they were sealed in 300 ml polypropylene containers and stored for a minimum period of 30 d to allow ^{226}Ra to come into equilibrium with its daughters taking care to prevent ^{222}Rn escaping from the container.

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the samples were determined using the gamma spectrometry employing a 38% relative efficiency p-type low background HPGe detector having an energy resolution of 2.1 keV at 1.33 MeV (CANBERRA, USA). The spectrum was acquired and analyzed using a 16 K multichannel analyzer (Multiport, CANBERRA) and GENIE-2000 software. The detector efficiency calibration was performed using the IAEA quality assurance reference materials: RG U-238, RG Th-232, RG K-1, and SOIL-6 procured from IAEA. The standard materials and samples were collected in containers of uniform size and type so that detection geometry remained the same. The samples were counted long enough to reduce the counting error. The ^{226}Ra activity was evaluated from the weighted mean of the activities of three photopeaks of ^{214}Bi (609.3, 1129.3, and 1764.5 keV) after applying the Compton corrections. In the case of ^{232}Th, one photopeak of ^{228}Ac (911.2 keV) and two photopeaks of ^{208}Tl (583.1 and 2614.5 keV) were used in the same way. The activity of ^{40}K was derived from the 1460.8 keV gamma line of this isotope [5]. The minimum detection levels (MDL) for the above detecting system were 0.62 Bq kg^{-1}, 2.46 Bq kg^{-1}, and 1.42 Bq kg^{-1}, respectively for ^{226}Ra,