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External dose measurements in the Eloor industrial area in the Ernakulam district of Kerala, India

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ABSTRACT

Background: Natural background radiation of a particular region is one of the distinctive factors defining the status of environment. Eloor Island is an industrial area in Ernakulam District of the state of Kerala, India. The indoor and outdoor gamma level measurements have been carried out for the region for evaluating the annual effective dose to the population residing in this area. ***Materials and Methods***: Measurements of indoor gamma dose were done for a whole year using Thermo Luminescent Dosimeters (TLDs) and GM tube based survey meters in forty five selected locations. The activity concentration of ^{232}Th, ^{238}U and ^{40}K in the samples were analyzed using gamma spectrometry. The outdoor external gamma ray dose rates were evaluated from the activity concentration of ^{40}K, ^{238}U and ^{232}Th in the soil samples collected from the study area. ***Results:*** The average indoor gamma dose measured using TLDs were found to be 1219 μGy y^{-1}. The measured activity in the soil samples had range from 92.5 Bq kg^{-1} to 792.8 Bq kg^{-1} for ^{232}Th, 9.2 Bq kg^{-1} to 114.6 Bq kg^{-1} for ^{238}U and 265.9 Bq kg^{-1} to 851.9 Bq kg^{-1} for ^{40}K. From the observed mean dose levels, the annual effective dose equivalent to population residing in the island has been estimated and is found to be 0.68 mSv y^{-1} for indoors and 0.32 mSv y^{-1} for outdoors. ***Conclusion:*** The annual effective dose equivalent to population estimated for indoor is found to be higher as compared to the global average the same for outdoor was found to be less when compared with the natural background gamma level reported by UNSCEAR for normal background areas.

Keywords: *Eloor island, indoor dose, outdoor dose, annual effective dose.*

INTRODUCTION

Background radiation is continuously present in the environment and it originates from a variety of natural and artificial sources. The worldwide average radiation dose for a human being from all sources is about 2.4 millisievert (mSv) per annum [(1)]. This exposure is mostly from naturally occurring radioactive materials (NORM) and cosmic radiation in the environment. Natural radiation exposure is of importance because it accounts for the largest contribution to the collective dose to the world population from all sources [(1)]. The indoor and outdoor absorbed dose rates are mainly due to natural ^{232}Th and ^{238}U along with their daughter products and the non-series ^{40}K, which give rise to external gamma dose as well as the inhalation doses. Human beings are exposed outdoors to the natural terrestrial radiation that originates predominantly from the upper 30 cm of the soil [(2)]. The presence of naturally occurring radioactive elements in the building materials causes external exposure inside dwellings [(3)].

The indoor exposure rate is more significant, since people spent 80% of their time indoors. A countrywide survey of outdoor natural gamma radiation in India using thermo luminescent dosimeter has yielded a national average value of 0.734 mSv y^{-1} as external terrestrial gamma background radiation, consisting of cosmic ray (0.355 mSv y^{-1}) and terrestrial component (0.379 mSv y^{-1}) [4].

Human activity involving earthen materials can result in technologically enhanced naturally occurring radioactive materials (TENORM). Experimental area of this study, Eloor Island, is located in the bank of Periyar river and is a home for a number of major and minor industries in operation. Twenty five percent industries of the state are located along the bank of river Periyar and the concentration of these industries is within a stretch of 5 Km in the Eloor-Edayar area. The plants processing NORM minerals have been operational for more than half a century. The major industries in the region produce fertilizers, insecticides, zinc and rare earths and majority of these discharge their treated effluents into the river Periyar and the surrounding neighborhood. The area is demarcated as one of the three 'toxic hotspots' in India [5]. Studies in the Periyar river on radioactivity distributions were reported earlier with emphasis on effluent discharges from the monazite industry [6 - 9] however, literature indicates that there is very scarce baseline information for radioactivity levels in the surrounding island environs. The objective of the present study was to measure the indoor and outdoor gamma dose in the Eloor island and hence to assess the annual effective dose to the population.

MATERIALS AND METHODS

Study area

The study area namely Eloor (commonly known as Udyogamandal) is an industrial area in Ernakulam district of Kerala state in India. The island has an area of 11.21 km^2 formed between two distributaries of river Periyar and is the largest industrial belt in Kerala. The region is located at a Latitude of 10^0 5' North and Longitude 76^0 16' East and is at an elevation of 4.3 m from the mean sea level. The Eloor panchayath (hamlet) has a population of about 30,000 and the panchayath is divided into 20 wards. There are nearly 8,245 houses in the entire area. Figure 1 shows the sketch of the study area.

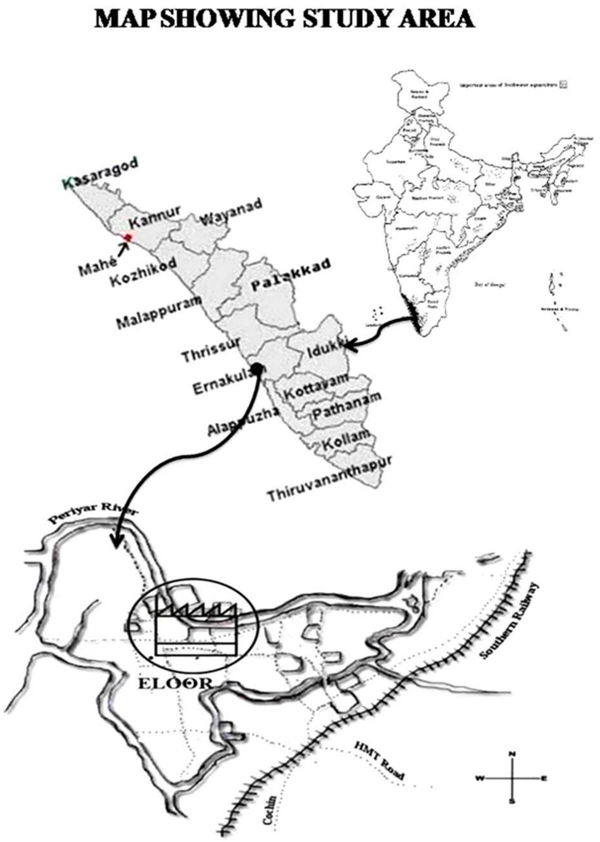

Figure 1. Sketch of the study area.

Eloor has more than 247 industries manufacturing a range of products like chemical-petrochemical, pesticides and insecticides, rare earth elements, rubber processing chemicals, fertilizers, zinc/chromium compounds and leather products. The environment of Eloor is much chemically polluted as a result of industrialization. It has been reported that the water bodies in the region are biologically polluted with presence of Cr, Mn, Co, Ni, Cu, Zn, Cd, Pb, Bi, As and Hg [10]. The two major industries of interest with respect to Naturally Occurring Radioactive Minerals (NORMs) are a fertilizer plant processing rock phosphate and the monazite processing plant, which has been in operation for the last 50 years. Apart from these industries, a zinc processing plant and a synthetic rutile production plant have been in operation for several years in the area. The investigations were carried out in 15 selected wards of Eloor Panchayat (among the total 20 wards in the panchayath, 5 wards were not covered due to poor inhabitation). From each ward 3 houses were selected for the external gamma dose measurements using TLDs and survey meter. Out of these 45 locations soil samples were collected from 20 selected locations within a radial distance of 3 km of the industrial area. Presumably, contamination to the soil would occur only in the neighboring area of the industry and its dump yards.

Methodology

Dose measurements

Ambient gamma dose rates were assessed in two methods using TLDs and survey meter.

The former method provides cumulative exposure assessment over a long period of time and it can be normalized to the annual external radiation dose. Secondly, direct measurements of gamma absorbed dose rates were carried out using a scintillometer based survey meter (UR705 manufactured by Nucleonix, India). Routine calibration was done for the survey meter with a ^{137}Cs standard source. Cross calibration with a different Radiation Survey meter and radioactive sources at Health Physics Unit, Indian Rare Earth's, Udyogamandal was also done. All measurements were made 1m above the ground level and the absorbed dose rates were estimated.

The measurements were carried out during the period September 2010 and August 2011 in four phases of three months each. Dwellings for the study were chosen so as to have a uniform distribution throughout the study area. While choosing the locations, the construction materials used in the house also were considered. In the present study $CaSO_4$:Dy based TLDs were used. The TLDs were deployed inside the pre-selected 45 dwellings and were kept undisturbed for a period of three months. TLDs were stuck to the walls in the indoor atmosphere at a height of 6feet. The TLDs were replaced with a fresh set so that each house is monitored for a whole year to take account of the seasonal variations of gamma dose rates, if any. During installation and retrieval of TLDs in the dwellings, ambient gamma dose rates were measured using the survey meter. While calculating the dose received by the population, the transit and storage of TLDs were taken into account. The correction for this exposure was done using control TLDs and appropriate deduction was made to arrive at the exposure pertaining to designated location. The retrieved TLDs were analyzed for dose measurements by a PC based TL reader in an inert atmosphere with a continuous flow of nitrogen gas. The exposure rates obtained were first normalized to represent annual values and the effective dose for the respective houses were estimated using conversion co-efficient of 0.7 Sv Gy^{-1} and indoor occupancy factor of 0.8 [(1)].

Soil analysis

To have an estimate of the external gamma dose rates from the primordial radionuclides in soil, samples of soil were collected from 20 locations in the area of study following the standard protocols. After removing extraneous materials like plant parts, pebbles, stones etc, the soil samples were dried, crushed and allowed to pass through 70mesh sieves to maintain uniformity in soil grain size. These samples were packed in a polythene container and were hermetically sealed to trap ^{222}Rn gas and its daughter products. These samples were stored for one month to attain secular equilibrium between the radionuclides in the uranium and thorium series. The activity concentration of ^{40}K, ^{238}U and ^{232}Th in the soil samples were analyzed using NaI(Tl) gamma ray spectrometer with 5”×4” planar detector coupled to a 1K multichannel analyzer with computer software (NETSWIN) for data acquisition and analysis. The energy response and counting efficiency of this spectrometric system was done periodically using IAEA reference materials RGU-1, RGTh-1 and RGK-1. Samples were counted for 20,000 s each. The activity concentration of ^{232}Th, ^{238}U and ^{40}K were determined from the integrated counts under the photo peak of the energy spectrum using gamma energies of 1461keV for ^{40}K, 1764 keV of ^{214}Bi for ^{238}U and 2614keV of ^{208}Tl for ^{232}Th and was calculated using the equation (1):

$$Activity(Bqkg^{-1}) = \frac{CPS \times 100 \times 100 \times 1000}{A \times E \times W} \quad (1)$$

The minimum detection level (MDL) for the detecting system for ^{40}K, was chosen to be 34Bqkg^{-1}, for ^{232}Th, 9.6 Bqkg^{-1} and for ^{238}U, 8 Bqkg^{-1}.

From the activity concentration of ^{40}K, ^{238}U, ^{232}Th, the absorbed gamma dose rate in air 1m above the ground level was calculated using the equation (2) given by UNSCEAR [11]

$$D = 0.462\ C_U + 0.604\ C_{Th} + 0.042\ C_K \quad (2)$$

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

From the absorbed dose rate, using the conversion factor 0.7 Sv Gy^{-1} and outdoor occupancy factor of 0.2 proposed by UNSCEAR [11] the annual effective dose to the population was estimated using the equation (3):

$$\text{Effective dose rate (mSv y}^{-1}) = D\ (\text{nGy h}^{-1}) \times 8760\ h \times 0.2 \times 0.7\ \text{Sv Gy}^{-1} \times 10^{-6} \quad (3)$$

RESULTS AND DISCUSSION

Indoor external gamma dose

The results of the analysis of mean indoor gamma dose measured using survey meter and the TLD in the study area are summarized in table 1. The TLD analysis was carried out for four phases, Phase 1 (September 2010 – November 2010), Phase 2 (December2010 – February 2011), Phase 3 (March 2011 – May 2011) and Phase 4 (June 2011 – August 2011). The summary of indoor dose obtained for different phases in the TLD analysis are shown in table 2.

The ambient indoor radiation levels measured using survey meter, when normalized to annual dose were found to vary from 1070.7 µGy y^{-1} to 1898.8 µGy y^{-1}with a mean value of 1449±177 µGy y^{-1}. The data obtained from the measurements using TLDs, the average annual dose taking all the four phases into account in the study area was estimated as 1219 ± 173 µGy y^{-1}. The comparison over different phases showed a gradual gradation in arithmetic mean from phase 1 with a dry climate to phase 4 which is rainy season (table 2). Figure 2 shows the frequency distribution of gamma dose in the dwellings as mesured by TLDs and survey meter. It is observed that most of the houses in the region had annual dose in the range of 1200µGy y^{-1} to 1300µGy y^{-1}. The gamma dose rates measured using TLDs in the present study are found to be higher by a factor of 2 as compared with the all India average of 604 µGy y^{-1} (table 3).

The indoor external dose depends on the type of building materials used. Most of the houses where measurements were carried out are cement plastered and having concrete roof or tiled roof. It is observed that the dose rate for all the four phases in houses with concrete and tiled roofs were similar. The houses when categorized under four classes according to the floor types (Marble, Mosaic, Red oxide, Cement) indicate that the dwellings with mosaic floor showed marginally higher indoor dose (1429 µGy y^{-1}) and the minimum was observed in the dwellings with Red oxide floor.

The correlation analysis of indoor external dose measured using survey meter and TLD are shown in figure 3. A positive correlation with correlation coefficient of 0.76 (R^2 = 0.58) was observed. The ratio between TLD and survey meter measurement were estimated and it was found to vary from 0.7 to 0.97. Higher values shown by the survey meter could be due to the interference of other types of ambient radiations detected by the survey meter.

The annual average effective dose equivalent in the indoor atmosphere to population in the region was estimated by making use of the conversion factor of 0.7Sv Gy^{-1} and the indoor occupancy factor 0.8 and was found to be 0.68±0.1 mSv y^{-1}. The obtained dose in the present study is higher as compared with the global average for annual exposure for indoor atmosphere of 0.41 mSv y^{-1} [11].

Outdoor external gamma dose

The activity concentration of ^{232}Th, ^{238}U and ^{40}K in Bqkg^{-1} in the soil samples analyzed are presented in table 4. The measured activity concentration varies from 92.5 Bqkg^{-1} to 792.8 Bqkg^{-1} with a mean value of 357.7±222 Bqkg^{-1} for ^{232}Th, 9.2 Bq kg^{-1} to 114.6 Bq kg^{-1} with mean value of 36.2±18 Bqkg^{-1} for ^{238}U and 265.9 Bqkg^{-1} to 851.9 Bqkg^{-1} with a mean value of 614.1±208 Bqkg^{-1} for ^{40}K. The mean activity concentration of ^{232}Th, ^{238}U and ^{40}K obtained in the present study was 7.9, 1 and 1.5 times the world average value and 5.6, 1.2, 1.5 times the Indian average values respectively [1, 11]. The comparisons of observed activity concentration in the present study with other reports in the literature are given in table 5.

Table 1. Summary of Indoor dose measured using survey meter and TLDs in the study area.

	Survey meter (µGy y^{-1})	TLD (µGy y^{-1})
Minimum	1070.7	901.2
Maximum	1898.8	1641
Median	1417.5	1220
AM±SD	1449±177	1219±173

Table 3. Comparison of mean indoor radiation dose in the study area with those reported in the other environments in the country.

Place	Dose (µGy y^{-1})
Gogi, Karnataka[12]	1051.2
Gudalore, South India[13]	1195.3
Coonoor, South India[14]	1385.8
Indian average [14]	604
Ullal Beach[15]	2067
Present study	1221

Table 2. Indoor dose measured for four phases using TLDs (µGy y^{-1}).

	Phase -1 (September - November 2008)	Phase -2 (December 2008 - February 2009)	Phase -3 (March - May 2009)	Phase -4 (June - August 2009)
Minimum	732.0	866.9	817.1	775.9
Maximum	1873.9	1593.0	1778.1	1640.9
Median	1313.0	1241.0	1153.9	1113.1
AM±SD	1274±252	1257±193	1214±231	1141±184

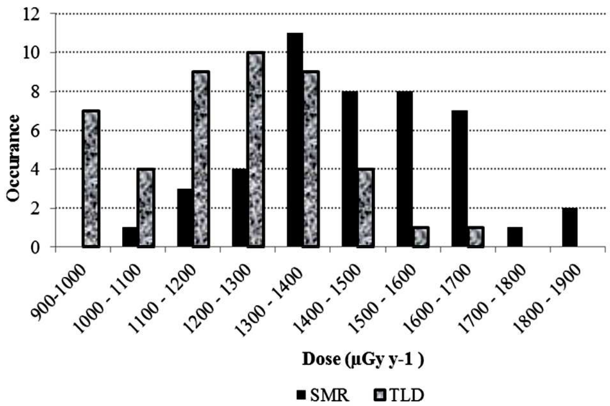

Figure 2. Frequency distribution of dose as measured by TLD and survey meter.

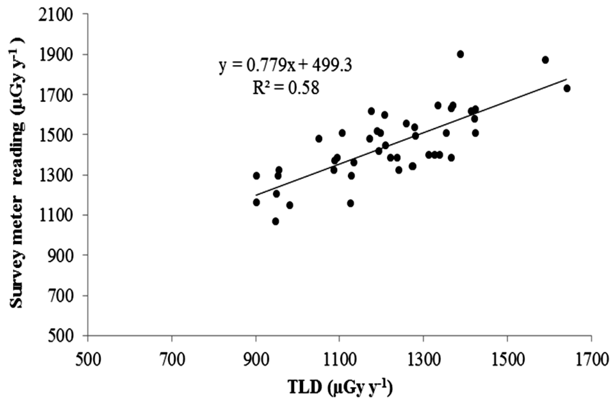

Figure 3. Scatter plot depicting correlation between the mean annual dose rates as measured by TLD and survey meter.

Table 4. Activity concentration of natural radionuclides, their corresponding absorbed dose rate and measured dose rate in the study area.

	^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	Absorbed gamma dose rate (nGy h^{-1})	Measured gamma dose rate (nGy h^{-1})
Minimum	265.9	9.2	92.5	76.5	121.8
Maximum	851.9	114.6	792.8	532.6	364.3
Median	637.3	24.9	271	223.4	193.4
AM±SD	614.1±208	36.2±18	357.7±222	262.4±144	218.9±73

Table 5. Comparison of activity concentration of natural radionuclides obtained in the present study and other parts of the world.

	^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	Absorbed gamma dose rate (nGy h^{-1})
World average (11)	420	33	45	59
China (1)	440	84	41	62
Japan (1)	310	29	28	53
Indian average (1)	400	29	64	56
Coastal Karnataka (2)	122	36	31.1	41.7
Ullal (13)	268	546	2971	2212
Present study	614.1	36.2	357.7	262.4

The absorbed gamma dose rate in air at 1m above the ground evaluated from the activity concentration of ^{232}Th, ^{238}U and ^{40}K varies from 76.5 nGy h^{-1} to 532.6 nGy h^{-1} with a mean value of 262.4 nGy h^{-1}. The mean absorbed gamma dose rate is found to be higher than the world average value of 51 nGy h^{-1} (11). The relative contribution of natural gamma emitters to the total gamma dose rate indicates that, the ^{232}Th contributes about 82.6% (216.8 nGy h^{-1}) of the dose rate which is considered to be high when compared ^{238}U and ^{40}K, which contributes only 5.9% and 9.8% respectively to total dose in the study area.

An attempt was made to co-relate the indoor dose measured using TLDs and outdoor absorbed dose rate obtained in the study area and is shown in figure 5. It shows a co relation coefficient of 0.65(R^2= 0.42). Upon comparing the indoor external dose measured using TLD to the outdoor external dose rate evaluated from the activity concentration of radionuclides, the outdoor dose rate obtained was higher than indoor dose rates by a factor of 1.8. This may be due to the fact that major portion of the indoor dose is contributed by the natural radioactivity present in the building material and outdoor dose mainly depends on the activity concentration of natural radionuclides present in the soil. The activity concentration of natural radionuclides in the soil in the present study shows a wide variation among the locations. These may be due to some historic reasons such as phosphogypsum landfills done earlier or natural presence of monazite patches.

The annual effective dose for the outdoor environment calculated from the absorbed dose rate using the equation 2 in the study area was found to be 0.32 mSv y^{-1}. This was found to be higher when compared to the natural background gamma level 0.07 mSv y^{-1} reported by UNSCEAR (11) for normal background areas.

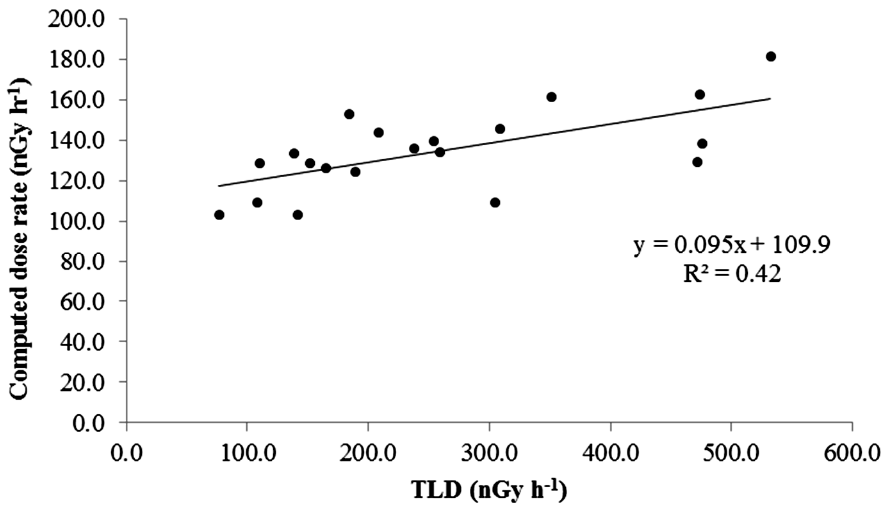

Figure 5. Co-relation between computed gamma outdoor dose rate and indoor dose rate measured using TLDs.

CONCLUSION

The preset investigations showed that the indoor and outdoor background radiation levels in the Eloor Island was relatively higher when compared with other reported values. The annual effective dose equivalent to population estimated for indoor is found to be higher when compared to the global average for indoor annual exposure from natural sources, whereas the outdoor annual effective dose equivalent was found to be lesser when compared to the natural background gamma level reported by UNSCEAR for normal background areas. There is very scarce baseline information for ambient gamma dose levels in this region and this study has made a significant contribution for setting up reference levels for studies pertaining to background radiation levels of this region in future.

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Conflict of interest: *Declared none.*

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