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Spatial distribution and lifetime cancer risk due to gamma radioactivity in Yelagiri Hills, Tamilnadu, India

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ABSTRACT
The spatial distribution of natural radioactivity due to uranium, thorium and potassium was investigated in soils from the undisturbed areas in Yelagiri Hills, Tamilnadu, India by Isodose map. The radiological hazards due to natural radionuclides content such as representative level index (RLI), activity utilization index (AUI), excess lifetime cancer risk (ELCR) and internal radiation hazards (Hin) of the soil samples in this area were calculated. The calculated radiological hazard parameters are compared with different countries of the world. The calculated range of ELCR is 0.326 × 10⁻³ to 1.067 × 10⁻³ with an average of 0.700 × 10⁻³ for soils. This average value of ELCR is more twice than the world average (0.290 × 10⁻³). A correlation analysis was made between measured dose rate and individual radionuclides, in order to delineate the contribution of the respective nuclides toward the dose rate. The U/Th concentration ratio in surface soil samples ranged from 0.05 to 1.72 with an average of 0.43 which is more higher (80%) than the world average of 0.26. The application of cluster analysis (CA) and principal component analysis (PCA), coupled with Pearson correlation coefficient analysis, were utilized to analyze the data, identify and clarify between the radiological parameters to know the existing relations. The CA and PCA results showed that the former method yielded three distinctive groups of the soil variables.
1. Introduction

The radioactivity level from the natural radionuclides is termed as background radiation which will depend on the amount of the radioactive materials in the environment. The background radiation can be high if the environment is polluted either from man-made or natural activities. Materials from the deposit may be brought to the surface soil through processes such as weathering of rocks and soil formation. They can also leach into the groundwater system, contaminate it, and lead to pollution far away from the source.

Natural radioactivity arises mainly from the primordial radionuclides, such as $^{40}$K and the radionuclides from $^{238}$U and $^{232}$Th series and their decay products, which are present at trace levels in all ground formations [1]. Monitoring the release of gamma radiation from natural radionuclides is important to protect the humans from lung cancer. The main sources of gamma radiations are due to two major radionuclide chains: uranium–radium and thorium. A geological and geographical condition of the study area determine the radioactivity and the associated external exposure due to gamma radiation at different levels in the soils of each region in the world [2–4].

The data will offer useful and necessary information in the monitoring of environmental contamination which will provide appropriate and better protection guidelines to the public.

The distribution of radionuclide concentration reflects migration of uranium and thorium under surface soil condition. The ability of hydrogenous migration falls in the order $U > Ra > Th$. Uranium is able to remain in soluble state for a long time and gets migrated by flow of streams or river to a long distance. Horizontal transfer of uranium and thorium is dominated by interchange of sorption and desorption [5]. Unfortunately rapid increasing of population and usage of fertilizers for agriculture day by day contaminate the soils. Due to one of the main tourism places in Tamilnadu, point and nonpoint pollution sources are dominated in study area. Hence it is necessary to determine the concentration levels of the $^{238}$U and $^{232}$Th as well as $^{40}$K in the soil from Yelagiri hills, Tamilnadu, India and to analyze the spatial distribution of natural radionuclides by Isodose map with statistical approach.

2. Previous work

In an earlier work, activity concentration of natural radionuclide that in different locations of Yelagiri Hills is reported by Ravisankar et al. [4]. They indicated that average activity concentration of $^{232}$Th in that study was 1.19 times higher than world median value while the activity of $^{238}$U and $^{40}$K was found to be lower and also major gamma radiation exposure to humans in Yelagiri Hills due to enrichment of $^{232}$Th content in soils [4]. The present work is a continuation of the previous research work in Yelagiri Hills, Tamilnadu to study the spatial distribution of natural radionuclide and the application of Multivariate statistical method to analyze the data, identify and clarify between the radiological parameters to know the existing relations.

Fig. 1 – Soil samples collected at different sampling points of Yelagiri Hills, Tamilnadu, India.
3. Geology of study area

Yelagiri is a hill station/village in Vellore district of Tamilnadu, India, situated off the Vaniyambadi–Tirupattur road. Located at an altitude of 1410 m above Mean Sea Level and spread across 30 km², the Yelagiri village (also spelled Elagiri at times) is surrounded by orchards, rose-gardens, and green valleys. Yelagiri comprises of 14 hamlets and a number of temples spread over a couple of hills. The highest point in Yelagiri is the Swamimalai Hill, standing at 4338 ft: Swamimalai is a popular destination for trekkers. The hill provides a good number of trekking trails through thick reserve forests. Mangalam, a small village, is at the base of this hill. There are other trekking options that include smaller peaks like Javadi Hills, Palamathi Hills etc.

4. Materials and methods

4.1. Sampling methodology

The soil profiles were sampled using an automatic core driller. Cores extruded and sectioned at 10 cm diameter and 25 cm depth were used to take soil samples [6]. The soil samples

| Sample location Id | Locations     | Activity concentration (Bq kg⁻¹) | RLI (Bq kg⁻¹) | AUI | AGDE (μSv y⁻¹) | ELCR × 10⁻³ | Internal radiation hazards (Hin) |
|--------------------|---------------|---------------------------------|---------------|-----|----------------|--------------|--------------------------------|
| YS1                | Pavendar bend | BDL                            |               |     |                |              |                                |
| YS2                | Bharathiyar bend | BDL                            |               |     |                |              |                                |
| YS3                | Thiruvalluvar bend | BDL                            |               |     |                |              |                                |
| YS4                | Ilango bend     | 18.93 ± 8.25                   | 83.77 ± 8.03  | 1137 ± 44.30 | 1.63 | 1.282 765.67 | 0.863                           |
| YS5                | Kambar bend     | 25.55 ± 7.20                   | 36.24 ± 6.31  | 913.95 ± 39.04 | 1.06 | 0.750 517.41 | 0.588                           |
| YS6                | Kalibar bend    | 6.24 ± 6.63                    | 28.45 ± 6.12  | 1391.6 ± 42.96 | 1.16 | 0.517 575.17 | 0.639                           |
| YS7                | Oiyar bend      | 23.35 ± 7.12                   | 38.95 ± 6.34  | 872.86 ± 38.28 | 1.05 | 0.759 509.04 | 0.578                           |
| YS8                | Paari bend      | 18.45 ± 9.04                   | 89.48 ± 8.82  | 1025.2 ± 46.59 | 1.62 | 1.337 752.95 | 0.850                           |
| YS9                | Kaari bend      | 33.39 ± 9.49                   | 114.75 ± 9.21 | 936.11 ± 45.95 | 1.91 | 1.773 867.76 | 0.998                           |
| YS10               | Oori bend       | 22.81 ± 5.25                   | 1143.8 ± 36.54| 0.91 | 0.371 454.50  | 0.502                     |
| YS11               | Aayai bend      | 21.2 ± 8.59                    | 100.42 ± 8.47 | 1128.8 ± 44.92 | 1.81 | 1.503 839.71 | 0.737                           |
| YS12               | Adiyaman bend   | 15.76 ± 7.96                   | 71.31 ± 7.69  | 1250.2 ± 44.83 | 1.56 | 1.111 739.34 | 0.831                           |
| YS13               | Nali bend       | 28.05 ± 6.41                   | 1455.5 ± 45.19| 1.15 | 0.460 574.28  | 0.634                     |
| YS14               | Began bend      | 26.06 ± 5.88                   | 2165.5 ± 48.52| 1.56 | 0.495 788.90  | 0.869                     |
| YS15               | Arthanavoor     | 41.45 ± 6.72                   | 1137.8 ± 41.88| 1.10 | 0.596 530.53  | 0.588                     |
| YS16               | Kottaivoor      | 10.1 ± 6.45                    | 43.34 ± 6.10  | 2105.4 ± 46.83 | 1.76 | 0.792 873.47 | 0.970                           |
| YS17               | Mangalam        | 13.13 ± 6.48                   | 29.52 ± 5.85  | 1219.1 ± 39.97 | 1.11 | 0.580 546.76  | 0.612                           |
| YS18               | Meotakalli      | 23.76 ± 8.95                   | 13.78 ± 17.21 | 1263 ± 72.55  | 1.04 | 0.491 527.60  | 0.594                           |
| YS19               | Pothvoor        | 23.79 ± 8.38                   | 61.69 ± 16.44 | 700.93 ± 58.66 | 1.18 | 1.023 551.47 | 0.628                           |
| YS20               | Killivoor       | 34.93 ± 9.16                   | 46.79 ± 16.71 | 2102.8 ± 76.73 | 1.91 | 1.059 948.10  | 1.067                           |
| YS21               | Nilavoor        | 39.89 ± 5.64                   | 57.6 ± 8.64   | 630.41 ± 32.08 | 1.19 | 1.117 561.98  | 0.648                           |
| YS22               | Meotakanimvoor  | 39.55 ± 5.55                   | 50.24 ± 8.31  | 625.09 ± 31.46 | 1.11 | 1.024 528.49  | 0.610                           |
| YS23               | Pallanvoor      | 49.72 ± 7.00                   | 35.95 ± 9.85  | 261.33 ± 33.06 | 0.81 | 0.915 385.89  | 0.457                           |
| YS24               | Thayaloor       | 20.45 ± 4.95                   | 44.47 ± 9.26  | 983.08 ± 39.25 | 1.16 | 0.808 557.76  | 0.630                           |
| YS25               | Putthoor        | 53.23 ± 7.07                   | 89.89 ± 10.89 | 557.88 ± 36.27 | 1.55 | 1.624 715.40  | 0.829                           |
| Average            |               | 19.16 ± 4.85                   | 48.56 ± 1148.68| 1.29 | 0.857 621.39  | 0.700                     | 0.528                          |
were collected from 25 sites with the only constraint that no sampling site should be taken to a field boundary, a road, a tree, a building or other obstruction. The sample collected at different locations of Yelagiri Hills, Tamilnadu is shown in Fig. 1. For each soil sample collected, an area of 1 m × 1 m was marked and carefully cleared of debris to a few centimeters depth. The collected samples were then placed in labeled polythene bags and transferred to the laboratory for preparation and analysis. These samples were mixed together thoroughly, in order to obtain a representative sample of that area.

4.2. Sample preparation

In the laboratory, the soil samples were sieved by a 2 mm mesh to remove larger objects and then ground using mortar and pestle to fine powder in order to have the same matrix as the reference sample. After that, the samples were dried in an oven at a temperature around 105 °C for two hours until constant weights were attained and then placed in desiccators to avoid moisture absorption. The homogenized sample was packed in a standard 250 ml airtight PVC plastic container and sealed using silicon and plastic tapes air tight. The samples were left for a minimum of 28 days for radioactive secular equilibrium between $^{222}$Rn-radon gas and its decay products ($^{214}$Pb, $^{214}$Bi, and $^{226}$Ra), from the $^{238}$U decay series to be acquired [7].

4.3. Radioactivity measurements

The concentrations of natural radioactivity in soil samples were determined using a $3' \times 3'$ NaI (Tl) gamma ray system. The detector was shielded by 15 cm thick lead on all sides including the top to reduce background due to cosmic ray component by almost 98%. The inner sides of the lead shielding are lined by 2 mm thick cadmium and 1 mm thick copper to cut off lead X-rays and cadmium X-rays respectively. This graded lining shield further reduces the background especially in the low energy region. Standard sources of the primordial radionuclides obtained from IAEA in the same geometry and having the same density, as that of the prepared soil samples, were used to determine the efficiency of the detector for various energies in the prescribed geometry. The soil samples were placed on the top of $3' \times 3'$ NaI (Tl) crystal and using the gamma ray spectrometer and multichannel analyzer, count spectra were obtained for each of the soil sample. Each radionuclide can be detected in either direct or indirect way. The radioisotope $^{40}$K emits gamma ray with an energy of 1.461 MeV. Hence the determination of $^{40}$K is considered as direct. The determination of $^{238}$U depends on the detection of the $^{214}$Bi radionuclide which is a member of the $^{238}$U decay series emitting an energy of 1.764 MeV. Therefore, the detection of $^{238}$U is indirect. The determination $^{232}$Th concentration is indirect as referred to the $^{208}$Tl radionuclide with an energy of 2.615 MeV, originating from the $^{232}$Th decay series. The concentration of U, Th and K is measured in Bq kg$^{-1}$ and reported by Ravisankar et al. [4].

The minimum detectable activity (MDA) of each of the three primordial radionuclides was determined from the background radiation spectrum obtained for the same counting time as was done for the soil samples and is estimated as 2.15 Bq kg$^{-1}$ for $^{232}$Th, 2.22 Bq kg$^{-1}$ for $^{238}$U and 8.83 Bq kg$^{-1}$ for $^{40}$K. The sealed containers were left for at least 4 weeks (>7 half life’s of $^{222}$Rn) before counting by gamma ray spectrometry in order to ensure that the daughter products of $^{226}$Ra up to $^{210}$Po and $^{228}$Th up to $^{208}$Pb achieve equilibrium with their respective parent radionuclides. All the soil samples were subjected to gamma ray spectral analysis with a counting time of 20,000 s.

![Fig. 3 – Soil sample location Id versus activity utilization index (AUI) & internal hazard indices (Hin).](image-url)
4.4. Multivariate statistical analysis

Multivariate statistical analysis (Pearson’s correlation analysis, Cluster analysis and Factor analysis) has been carried out to find out the interrelation among the parameters obtained from natural radionuclides. In this work main statistical software ‘Statistical program for the Social Science (SPSS/PC)’ was used for statistical analysis.

4.5. Spatial distribution of radioactivity

The Spatial distribution of radioactivity from soils due to naturally occurring radionuclides (238U, 232Th and 40K) is studied in Yelagiri Hills, Tamilnadu using isodose map which is made by SURFER (software version 8).

5. Results and discussions

5.1. 238U, 232Th and 40K activities

The results for the activity concentrations of natural radionuclides 238U, 232Th and 40K in soil samples of different locations of Yelagiri Hills, Tamilnadu are reported in Table 1. The activity concentrations of 238U, 232Th and 40K range from <2.17 to 53.23 Bq kg⁻¹, 13.54–114.75 Bq kg⁻¹ and 261.11–2207.3 Bq kg⁻¹, respectively. Except for 4 locations the obtained results for 238U have lower values of activity concentrations, when compared with worldwide average value (35 Bq kg⁻¹ for 238U) of this radionuclide in the soil [5]. Similarly except 9 locations, the obtained results for 232Th have higher values of activity concentrations, when compared with worldwide average value (30 Bq kg⁻¹ for 232Th, respectively) of this radionuclide in the soil [5]. Except for one location, the obtained results for 40K have higher value than the worldwide median values (400 Bq kg⁻¹). The lowest value, of 261.11 Bq kg⁻¹ of 40K, was found in the soil sample from the Pallakanvoor village of Yelagiri Hills and the high value of 207.3 (Bq kg⁻¹) in the soil sample from the Pavender bend of Yelagiri. The average activity concentration of 232Th and 40K in the present study is 1.38 and 2.86 times higher than world median value while the activity of 238U is found to be lower.

5.2. Representative level index (RLI)

The level of gamma radioactivity associated with different concentrations of some specific radionuclides is known as the representative level index [8–12] which is given as [12]
Table 3 – Pearson correlation matrix among the radiological variables. Bold values in the table represent the positive correlation between the radiological variables.

| Variables | 238-U | 232-Th | 40-K | RLI | AUI | AGDE | ELCR | H_{in} |
|-----------|-------|--------|------|-----|-----|------|------|-------|
| 238-U     | 1     |        |      |     |     |      |      |       |
| 232-Th    | 0.495 | 1      |      |     |     |      |      |       |
| 40-K      | -0.514| -0.239 | 1    |     |     |      |      |       |
| RLI       | 0.202 | 0.681  | 0.522| 1   |     |      |      |       |
| AUI       | 0.704 | 0.961  | -0.274| 0.676| 1   |      |      |       |
| AGDE      | 0.194 | 0.619  | 0.575| 0.996| 0.629| 0.998| 1    |       |
| ELCR      | 0.542 | 0.795  | 0.232| 0.931| 0.860| 0.897| 0.921| 1     |

\[ RLI = \frac{1}{150} A_U + \frac{1}{100} A_{Th} + \frac{1}{1500} A_K \]  

where \( A_{Th}, A_U \) and \( A_K \) are the average activity concentration of \( ^{232}\text{Th}, ^{238}\text{U} \) and \( ^{40}\text{K} \) in Bq kg\(^{-1}\), respectively. The calculated RLI values for the samples under investigation are given in Table 1. The representative level index varies from 0.60 to 1.91 with an average of 1.29. It is clear that the Yelagiri soil samples are upgraded in the study area. Fig. 2 shows the sample location Id and representative level index (RLI). The comparison of RLI with different countries of the world is given in Table 2.

5.3. Activity utilization index (AUI)

In order to facilitate the calculation of dose rates in air from different combinations of the three radionuclides in soils and by applying the appropriate conversion factors, an activity utilization index (AUI) is constructed that is given by the following expression [13]

\[ AUI = \left( \frac{C_U}{50 \text{ Bq/kg}} \right) f_U + \left( \frac{C_{Th}}{50 \text{ Bq/kg}} \right) f_{Th} + \left( \frac{C_K}{500 \text{ Bq/kg}} \right) f_K \]  

where \( C_{Th}, C_U \) and \( C_K \) are actual values of the activities per unit mass (Bq kg\(^{-1}\)) of \( ^{232}\text{Th}, ^{238}\text{U} \) and \( ^{40}\text{K} \) in the building materials considered; \( f_{Th} \) (0.604), \( f_U \) (0.462) and \( f_K \) (0.041) are the fractional contributions to the total dose rate in air due to gamma radiation from the actual concentrations of these radionuclides. In the NEA [9] Report, typical activities per unit mass of \( ^{232}\text{Th}, ^{238}\text{U} \) and \( ^{40}\text{K} \) in soils \( C_{Th}, C_U \) and \( C_K \) are referred to be 50, 50 and 500 Bq kg\(^{-1}\), respectively. The activity utilization of the soil samples is calculated using equation (2). The calculated values vary from 0.26 (Thiruvalluvlar bend) to 1.773 (Kaari bend) with an average of 0.857. This value shows that AUI < 2, which corresponds to an annual effective dose < 0.3 mSv/y [14]. This indicates that Yelagiri soil samples can be used as one of the safe building material. Fig. 3 shows the sample location Id and activity utilization index (AUI).

5.4. Annual gonadal dose equivalent (AGDE)

In the same context, the activity bone marrow and the bone surface cells are considered as the organs of interest by UNSCEAR [15]. Therefore, the annual gonadal dose equivalent (AGDE) due to the specific activities of \( ^{238}\text{U}, ^{232}\text{Th} \) and \( ^{40}\text{K} \) was calculated using the following formula [16]

\[ \text{AGDE} (\mu\text{Sv y}^{-1}) = 3.09A_U + 4.18A_{Th} + 0.314A_K \]  

The AGDE values are presented in Table 1. As can be seen, the average value does not exceed the permissible recommended limits, indicating that the hazardous effects of these radionuclides are negligible. The obtained value of AGDE for the studied samples ranged from 294.34 to 948.10 with an average of 621.39 \( \mu\text{Sv y}^{-1} \). In literature, the world average value for AGDE was found to be 300 \( \mu\text{Sv y}^{-1} \) for soils [17]. However, obtained average value is more than twice the world average value for soil. Fig. 4 shows the sample location Id and annual gonadal dose equivalent (AGDE).

5.5. Excess lifetime cancer risk (ELCR)

Excess lifetime cancer risk (ELCR) is calculated using the following equation and presented in Table 1 [13]

\[ \text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \]  

where AEDE, DL and RF are the Annual Effective Dose Equivalent, duration of life (70 years) and risk factor (0.05 Sv\(^{-1}\)), respectively. Annual effective dose equivalent of each location were reported in earlier work [4]. For stochastic effects, ICRP 60 uses values of 0.05 for the public [18]. The calculated range of ELCR is 0.326 \( \times 10^{-3} \) to 1.067 \( \times 10^{-3} \) with an average of 0.700 \( \times 10^{-3} \) for soils. This average value of ELCR is more twice than the world average (0.290 \( \times 10^{-3} \)) [6]. Fig. 5 shows the sample location Id and Excess lifetime cancer risk (ELCR).

Table 4 – Rotated factor loading of the calculated radiological variables in soils of Yelagiri Hills, Tamilnadu, India.

| Variables | Component |
|-----------|-----------|
|           | 1         | 2         |
| 238-U     | 0.024     | 0.885     |
| 232-Th    | 0.509     | 0.773     |
| 40-K      | 0.701     | -0.698    |
| RLI       | 0.974     | 0.223     |
| AUI       | 0.493     | 0.863     |
| AGDE      | 0.993     | 0.117     |
| ELCR      | 0.984     | 0.273     |
| H_{in}    | 0.837     | 0.534     |

\% of Variance explained | 57.47 | 37.00 |
5.6. Internal radiation hazard indices ($H_{in}$)

In addition to the external exposure, radon and its short-lived products are also dangerous to the respiratory organs. The internal hazard index ($H_{in}$) is used to control the internal exposure to $^{222}$Rn and its radioactive progeny [19]. The internal exposure to radon and its daughter products is quantified by the internal hazard index ($H_{in}$), which was calculated using the following formula [19].

$$H_{in} = \frac{A_{U}}{185 \, \text{Bq/kg}} + \frac{A_{Th}}{259 \, \text{Bq/kg}} + \frac{A_{K}}{4810 \, \text{Bq/kg}}$$  \hspace{1cm} (5)

The calculated internal radiation hazard indices ($H_{in}$) of soil samples are given in Table 1. This $H_{in}$ values varies from 0.218 to 0.818 with average of 0.528. The recommended value of internal radiation hazard indices is less than 1. Therefore, these areas may not pose radiological risks to the inhabitants owing to harmful effects of ionizing radiation from the natural radionuclides in soil. Fig. 3 shows the sample location Id and internal radiation hazard indices ($H_{in}$). The comparison of $H_{in}$ with different countries of the world is given in Table 2.

6. Statistical analyses of the data

The univariate statistics was applied to obtain data and complete discussion is given in earlier work [4]. The simplicity of the univariate statistical analysis is obvious and likewise the fallacy of reductionism could be apparent [20]. In order to avoid this problem, multivariate analysis such as Pearson’s correlation and cluster analysis are used to explain the correlation amongst a large number of variables in terms of a small number of underlying factors without losing much information [21,22]. The intention underlying the use of multivariate analysis is to achieve great efficiency of data compression from the original data, and to gain some information useful in the interpretation of the environmental geochemical origin. This method can also help to simplify and organize large data sets to provide meaningful insight [23] and can help to indicate natural associations between samples and/or variables [24] thus highlighting the information not available at first glance.

This multivariate treatment of environmental data is widely and successfully used to interpret relationships among variables so that the environmental system could be managed...
In this work, radioactive measurements acquired by the spectrometric gamma technique were subjected to qualitative and quantitative statistical analyses in order to draw a valid conclusion regarding the nature and significance of the distribution of radioactive elements in soil samples of Yelagiri hills of Tamilnadu, India. The main statistical software in use was SPSS 16.0. The activity concentrations of natural radionuclides $^{238}$U, $^{232}$Th, $^{40}$K and obtained radiological data are taken for analysis.

### 6.1. Pearson’s correlation coefficients analysis of radioactive variables

Correlation analysis has been carried out, as a bivariation statistics in order to determine the mutual relationships and strength of association between pairs of variables through calculation of the linear Pearson correlation coefficient. Results for Pearson correlation coefficients between all the studied radioactive variables for Yelagiri soil samples are shown in Table 3.

The high good positive correlation coefficient was observed between $^{232}$Th and $^{238}$U because uranium and thorium decay series occur together in nature [26]. But very weak negative correlation coefficient was observed between $^{40}$K and $^{238}$U, $^{232}$Th since $^{40}$K origins are in different decay series. And also Representative level index (RLI), Annual gonadal dose equivalent (AGDE), Excess lifetime cancer (ELCR) and internal hazard indices ($H_i$) have high good positive correlation coefficients with $^{238}$U, $^{232}$Th and $^{40}$K which indicates that the radiological parameters exist due to high concentration of radionuclides.

### 6.2. Factor analysis

Factor analysis was carried out on the data set (8 variables as in the above analyses) to assess the relationship as per the procedure given in [13]. The rotated factor 1 and factor 2 values are reported in Table 4. Factor analysis yielded two factors with eigen value $>1$, explaining 94.47% of the total variance. From rotate space of component-1 and component-2 the first factor accounted for 57.47% of the total variance and mainly characterized by high positive loading of concentrations of $^{232}$Th, $^{40}$K. Factor-2 accounted for 37% of the total variance, which mainly consists of positive loading of $^{238}$U. From the overall factor analysis, it is seen that $^{232}$Th, $^{40}$K increase the radioactivity in the soils. Fig. 6 gives a Graphical representation of factor component 1 and component 2.

### 6.3. Cluster analysis

Cluster Analysis (CA) is a multivariate technique, whose primary purpose is to classify the objects of the system into categories or clusters based on their similarities, and the objective is to find an optimal grouping for which the observations or objects within each cluster are similar, but the clusters are dissimilar from each other. The dendrogram visually displays the order in which parameters or variables combine to form clusters with similar properties. The most similar objects are first grouped, and these initial groups are

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**Table 5 – U/Th ratio and Th/U ratio of all locations of Yelagiri Hills, Tamilnadu, India.**

| Sample location Id | Locations        | U/Th   | Th/U   |
|--------------------|------------------|--------|--------|
| YS1                | Pavendar bend    | 0.092  | 10.876 |
| YS2                | Bharathiyar bend | 0.107  | 9.378  |
| YS3                | Thiruvalluvar bend | 0.166 | 6.018  |
| YS4                | Ilango bend      | 0.226  | 4.425  |
| YS5                | Kambar bend      | 0.705  | 1.418  |
| YS6                | Kabilar bend     | 0.219  | 4.559  |
| YS7                | Oviyar bend      | 0.599  | 1.668  |
| YS8                | Paari bend       | 0.206  | 4.850  |
| YS9                | Kaari bend       | 0.291  | 3.437  |
| YS10               | Oori bend        | 0.099  | 10.138 |
| YS11               | Aayai bend       | 0.211  | 4.737  |
| YS12               | Adiyamn bend     | 0.221  | 4.525  |
| YS13               | Nali bend        | 0.080  | 12.467 |
| YS14               | Began bend       | 0.086  | 11.582 |
| YS15               | Arthanavoor      | 0.054  | 18.422 |
| YS16               | Kottaivoor       | 0.233  | 4.291  |
| YS17               | Mangalam         | 0.445  | 2.248  |
| YS18               | Meatokalli       | 1.724  | 0.580  |
| YS19               | Pothvoor         | 0.386  | 2.593  |
| YS20               | Kallivoor        | 0.747  | 1.340  |
| YS21               | Nilavoor         | 0.693  | 1.444  |
| YS22               | Meatakanivoo     | 0.787  | 1.270  |
| YS23               | Pallakanvoor     | 1.383  | 0.723  |
| YS24               | Thayaloor        | 0.460  | 2.175  |
| YS25               | Putthoor         | 0.592  | 1.689  |
| Average            |                  | 0.432  | 5.074  |

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**Fig. 8** – Scatter plot of the $^{238}$U versus measured dose rate.
emerged according to their similarities. Similarity is a measure of distance between clusters relative to the largest distance between any two individual variables. 100% similarity means the clusters were zero distance apart in their sample measurements, while the similarity of 0% means the cluster areas are disparate as the least similar region.

In this work cluster analysis is performed using average linkage method, to calculate the Euclidean distance between the variables. The derived dendrogram is shown in Fig. 7. In this dendrogram, all 8 parameters are grouped into three statistically significant clusters. Cluster-I consists of all measured radiological parameters except AGDE and uranium and thorium; cluster-II consists of only Annual Gonadal Dose Equivalent (AGDE) which is linked with uranium. Finally cluster-III consists of K with high Euclidean distance. All the clusters are formed on the basis of existing similarities. From cluster-I and Cluster-II the total level of the radioactivity mainly depends on $^{232}\text{Th}$ and $^{40}\text{K}$ concentrations. But Annual gonadal dose equivalent in Yelagiri Hills is due to the content of uranium.

7. Spatial distribution of gamma radiation levels

7.1. $^{238}\text{U}$ and $^{232}\text{Th}$ activity ratios

The calculated U/Th and Th/U ratio values of each locations are given in Table 5. The majority of locations fall on straight line with a slope 5.074 corresponding to Th/U ratio which is higher than the reported global Th/U ratio of 3.5 [27]. This greater value indicates that uranium is in equilibrium with its daughter [28]. Compared to the reported intercept of 0.3 mg/kg obtained by nationwide survey carried by an intercept of 6.5 mg/kg in present study indicates higher thorium content in the soil [29].

7.2. Correlation studies between the activity concentration and the measured dose rate

In order to find the existence of these radioactive nuclides together at a particular place, correlation studies were performed between combination of radionuclides like $^{238}\text{U}$ and $^{232}\text{Th}$ and $^{238}\text{U}$ and $^{40}\text{K}$. A very poor correlation observed between individual activity concentration of radionuclides which indicate individual results for any one of the radionuclide is not a good predictor of the concentration of the other [29]. Therefore an attempt was made to delineate the contribution of individual radionuclides toward the measured gamma dose rate in the study area irrespective of the cosmic radiation. Correlation studies were performed between the measured dose rates with the respective radionuclide activity concentration. A nearly good correlation existed between $^{232}\text{Th}$ (0.665) and $^{40}\text{K}$ (0.537) with the measured absorbed dose rate as shown in Figs. 9 and 10. Since the study area has thorium and potassium enriched soils and major portion of dose is contributed to $^{232}\text{Th}$ and $^{40}\text{K}$ series, a poor correlation existed between $^{238}\text{U}$ (0.184) with the measured dose rate as...
shown in Fig. 8. Hence gamma dose is negligible due to $^{238}$U series. The present $^{238}$U, $^{232}$Th and $^{40}$K activities in the surface soils are due to both natural and anthropogenic activities in the study area.

7.3. Gamma isodose map

The terrestrial gamma dose rates at each sampling locations are plotted using SURFER (software version 8). Fig. 11 shows the 3D plot of the gamma dose map of different locations of the study area with absorbed dose rate. The Enhanced activity areas are indicated with higher peaks with red color regions in the plotted map.

8. Conclusion

(i) The concentration of $^{232}$Th and $^{40}$K in the soil samples of Yelagiri hills is more that $^{238}$U which is less than the world average.
(ii) The obtained Th/U concentration ratio of 5.074 is higher compared to global ratio of 3.5 and the average U/Th concentration ratio of 0.43 which is higher than the world average of 0.26
(iii) The spatial distribution of radioactivity due to natural terrestrial radionuclides of $^{238}$U, $^{232}$Th, and $^{40}$K were studied by isodose map for surface soil samples and enhanced activity areas are indicated with higher peak regions in plotted map.
(iv) The average value ($0.700 \times 10^{-3}$) of ELCR is more twice than the world average value average ($0.290 \times 10^{-3}$).
(v) The values of internal hazard index determined in the soil samples is less than the recommended limit.

(vi) Methods of multivariate data analysis have proved to be a suitable tool for the interpretation of soil samples.

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Fig. 11 – The 3D plots of isodose map Yelagiri Hills showing the sampling locations.
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