ELSEVIER

Full Length Article

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

CrossMark

A. Chandrasekaran [a], R. Ravisankar [b,*], G. Senthilkumar [c],
K. Thillaivelavan [d], B. Dhinakaran [e], P. Vijayagopal [f], S.N. Bramha [f],
B. Venkatraman [f]

[a] Global Institute of Engineering & Technology, Vellore 632509, Tamilnadu, India
[b] Post Graduate and Research Department of Physics, Government Arts College, Thiruvanamalai 606603, Tamilnadu, India
[c] Department of Physics, University College of Engineering Arni, Arni 632317, Tamilnadu, India
[d] Department of Physics, Periayar Arts College, Cuddalore 607 001, Tamilnadu, India
[e] Department of Physics, Government Arts College, Chidambaram 608102, Tamilnadu, India
[f] Radiation Safety Section, Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, Tamilnadu, India

ARTICLE INFO

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 (H_{in}) 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

ELSEVIER | **Production and hosting by Elsevier**

whereas the latter one yielded the number of variables into two factors with 94.47% variance explanation.

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.
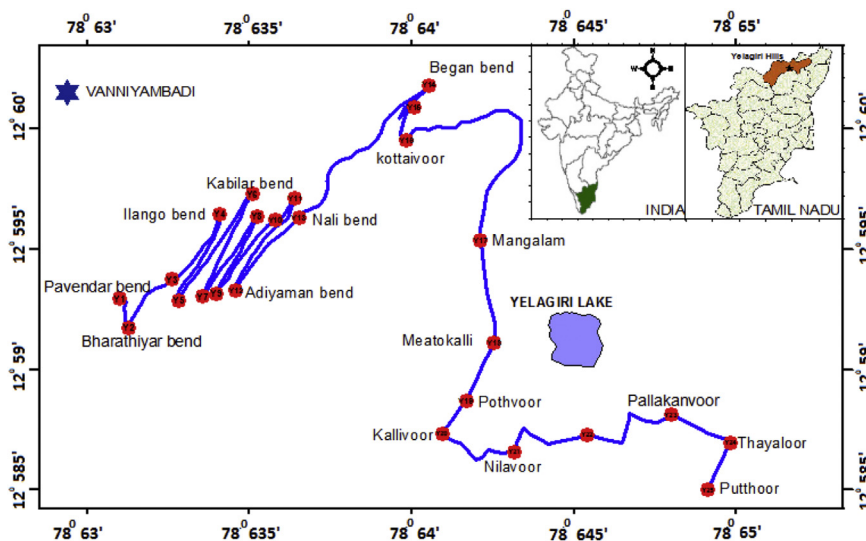

Fig. 1 – Soil samples collected at different sampling points of Yelagiri Hills, Tamilnadu, India.

Table 1 – Activity concentration, representative level index (RLI), activity utilization index (AUI), annual gonadal dose equivalent (AGDE), excess lifetime cancer risk (ELCR), internal radiation hazards (H_{in}) of soils of Yelagiri Hills, Tamilnadu, India.

Sample location Id	Locations	Activity concentration (Bq kg^{-1})			RLI (Bq kg^{-1})	AUI	AGDE (μSv y^{-1})	ELCR × 10^{-3}	Internal radiation hazards (H_{in})
		^{238}U	^{232}Th	^{40}K					
YS1	Pavendar bend	BDL	24.47 ± 6.11	2207.3 ± 50.53	1.57	0.480	795.38	0.876	0.553
YS2	Bharathiyar bend	BDL	21.1 ± 5.59	656.51 ± 33.29	0.60	0.310	294.34	0.326	0.218
YS3	Thiruvalluvar bend	BDL	13.54 ± 5.23	851.13 ± 34.90	0.65	0.235	323.85	0.357	0.229
YS4	Ilango bend	18.93 ± 8.25	83.77 ± 8.03	1137 ± 44.30	1.63	1.282	765.67	0.863	0.662
YS5	Kambar bend	25.55 ± 7.20	36.24 ± 6.31	913.95 ± 39.04	1.06	0.750	517.41	0.588	0.468
YS6	Kabilar bend	6.24 ± 6.63	28.45 ± 6.12	1391.6 ± 42.96	1.16	0.517	575.17	0.639	0.433
YS7	Oviyar bend	23.35 ± 7.12	38.95 ± 6.34	872.86 ± 38.28	1.05	0.759	509.04	0.578	0.458
YS8	Paari bend	18.45 ± 9.04	89.48 ± 8.82	1025.2 ± 46.59	1.62	1.337	752.95	0.850	0.658
YS9	Kaari bend	33.39 ± 9.49	114.75 ± 9.21	936.11 ± 45.95	1.91	1.773	876.77	0.998	0.818
YS10	Oori bend	BDL	22.81 ± 5.25	1143.8 ± 36.54	0.91	0.371	454.50	0.502	0.326
YS11	Aayai bend	21.2 ± 8.59	100.42 ± 8.47	1128.8 ± 44.92	1.81	1.503	839.71	0.948	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	0.620
YS13	Nali bend	BDL	28.05 ± 6.41	1455.5 ± 45.19	1.15	0.460	574.28	0.634	0.411
YS14	Began bend	BDL	26.06 ± 5.88	2165.5 ± 48.52	1.56	0.495	788.90	0.869	0.551
YS15	Arthanavoor	BDL	41.45 ± 6.72	1137.8 ± 41.88	1.10	0.596	530.53	0.588	0.397
YS16	Kottaivoor	10.1 ± 6.45	43.34 ± 6.10	2105.4 ± 46.83	1.76	0.792	873.47	0.970	0.660
YS17	Mangalam	13.13 ± 6.48	29.52 ± 5.85	1219.1 ± 39.97	1.11	0.580	546.76	0.612	0.438
YS18	Meatokalli	23.76 ± 8.95	13.78 ± 17.21	1263 ± 72.55	1.04	0.491	527.60	0.594	0.444
YS19	Pothvoor	23.79 ± 8.38	61.69 ± 16.44	700.93 ± 58.66	1.18	1.023	551.47	0.628	0.513
YS20	Kallivoor	34.93 ± 9.16	46.79 ± 16.71	2052.8 ± 76.73	1.91	1.059	948.10	1.067	0.796
YS21	Nilavoor	39.89 ± 5.64	57.6 ± 8.64	630.41 ± 32.08	1.19	1.117	561.98	0.648	0.569
YS22	Meatokanivoor	39.55 ± 5.55	50.24 ± 8.31	625.09 ± 31.46	1.11	1.024	528.49	0.610	0.538
YS23	Pallakanvoor	49.72 ± 7.00	35.95 ± 9.85	261.11 ± 33.06	0.81	0.915	385.89	0.457	0.462
YS24	Thayaloor	20.45 ± 4.95	44.47 ± 9.26	983.08 ± 39.25	1.16	0.808	557.76	0.630	0.487
YS25	Putthoor	53.23 ± 7.07	89.89 ± 10.89	557.88 ± 36.27	1.55	1.624	715.40	0.829	0.751
Average		19.16	48.56	1146.88	1.29	0.857	621.39	0.700	0.528

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 km^2, 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
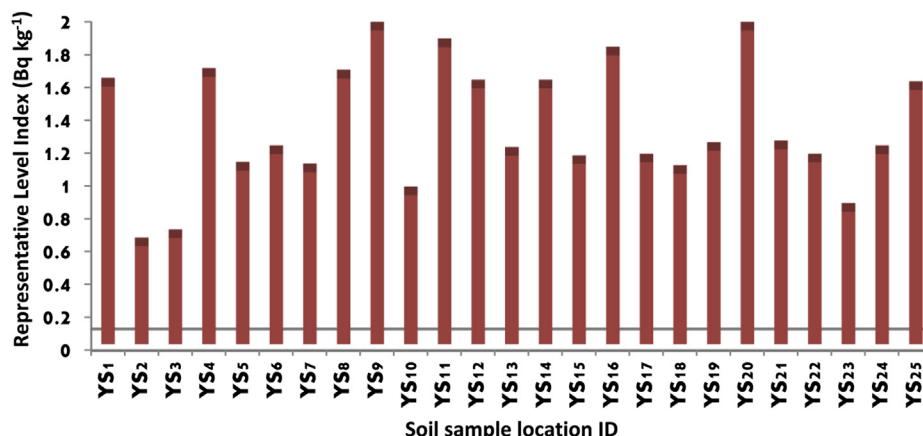
Fig. 2 − Soil sample location Id versus representative level index (Bq kg^{-1}).

Table 2 – Comparison of mean value of ELCR, RLI and H_{in} of present study with different countries of the world.

Country	Radiological parameters			References
	RLI	ELCR $\times 10^{-3}$	H_{in}	
China (Zhejiang)	1.4	–	–	[8]
Syria	0.5	–	–	[7]
Bangladesh (Southern part)	1.6	–	0.71	[10]
Nigeria	–	–	0.18–0.37	[30]
Malaysia	–	–	1.13–4.491	[31]
Turkey (Kirklareli)	–	0.5	–	[18]
World	1.0	0.29	1.0	[7]
Present study	1.29	0.70	0.52	–

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″ × 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″ × 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}Pb 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.
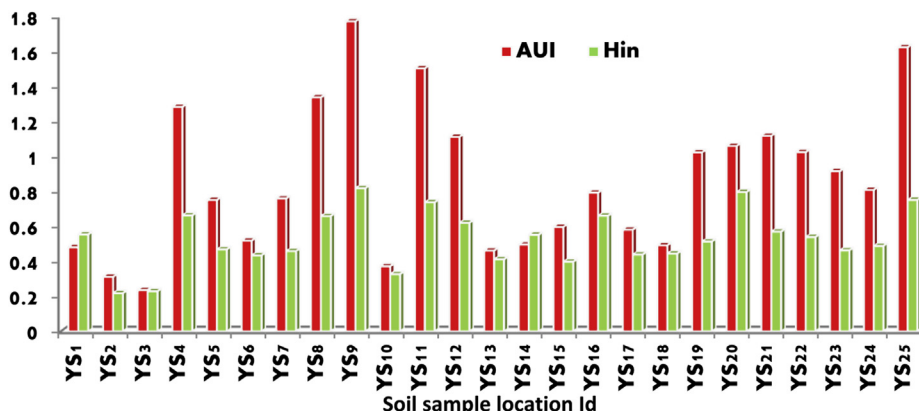
Fig. 3 – Soil sample location Id versus activity utilization index (AUI) & internal hazard indices (H_{in}).
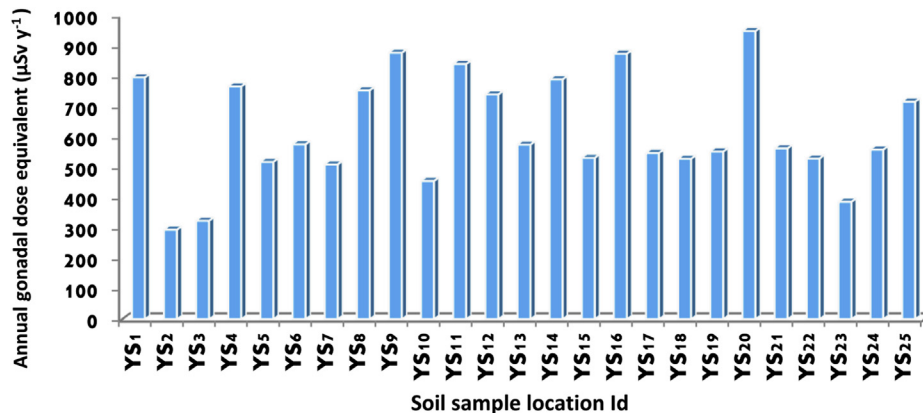
Fig. 4 – Soil sample location Id versus annual gonadal dose equivalent (μSv y^{-1}).

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 (^{238}U, ^{232}Th and ^{40}K) is studied in Yelagiri Hills, Tamilnadu using isodose map which is made by SURFER (software version 8).

5. Results and discussions

5.1. ^{238}U, ^{232}Th and ^{40}K activities

The results for the activity concentrations of natural radionuclides ^{238}U, ^{232}Th and ^{40}K in soil samples of different locations of Yelagiri Hills, Tamilnadu are reported in Table 1. The

activity concentrations of ^{238}U, ^{232}Th and ^{40}K 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 ^{238}U have lower values of activity concentrations, when compared with worldwide average value (35 Bq kg^{-1} for ^{238}U) of this radionuclide in the soil [5]. Similarly except 9 locations, the obtained results for ^{232}Th have higher values of activity concentrations, when compared with worldwide average value (30 Bq kg^{-1} for ^{232}Th, respectively) of this radionuclide in the soil [5]. Except for one location, the obtained results for ^{40}K have higher value than the worldwide median values (400 Bq kg^{-1}). The lowest value, of 261.11 Bq kg^{-1} of ^{40}K, was found in the soil sample from the Pallakanvoor village of Yelagiri Hills and the high value of 2207.3 (Bq kg^{-1}) in the soil sample from the Pavender bend of Yelagiri. The average activity concentration of ^{232}Th and ^{40}K in the present study is 1.38 and 2.86 times higher than world median value while the activity of ^{238}U 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]
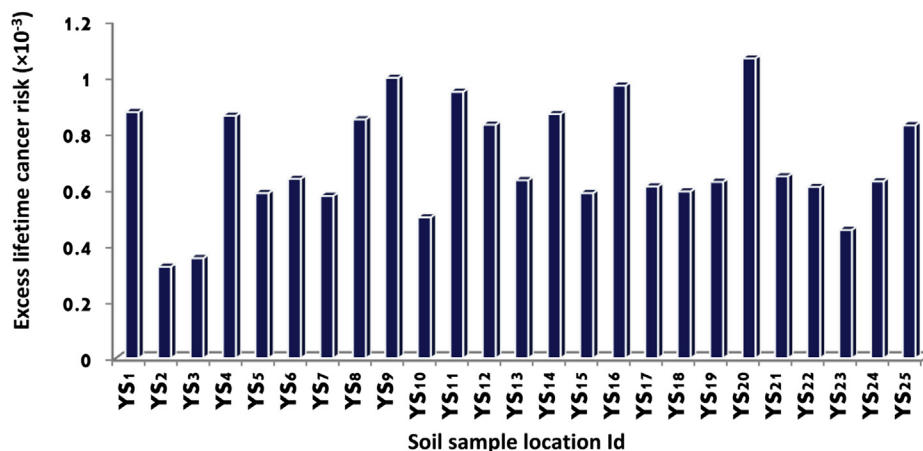

Fig. 5 – Soil sample location Id versus excess lifetime cancer risk ($\times 10^{-3}$).

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	**0.139**	**0.586**	**0.618**	**0.992**	**0.587**	1		
ELCR	**0.194**	**0.619**	**0.575**	**0.996**	**0.629**	**0.998**	1	
H_{in}	**0.542**	**0.795**	**0.232**	**0.931**	**0.860**	**0.897**	**0.921**	1

$$\text{RLI} = \frac{1}{150}A_U + \frac{1}{100}A_{Th} + \frac{1}{1500}A_K \qquad (1)$$

where A_{Th}, A_U and A_K are the average activity concentration of ^{232}Th, ^{238}U and ^{40}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 slightly exceed the upper limit for RLI which is unity [12] and it indicates that the 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]

$$\text{AUI} = \left(\frac{C_U}{50\ \text{Bq/kg}}\right)f_U + \left(\frac{C_{Th}}{50\ \text{Bq/kg}}\right)f_{Th} + \left(\frac{C_K}{500\ \text{Bq/kg}}\right)f_K \qquad (2)$$

where C_{Th}, C_U and C_K are actual values of the activities per unit mass (Bq kg^{-1}) of ^{232}Th, ^{238}U, and ^{40}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}Th, ^{238}U, and ^{40}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 0.235 (Thiruvalluvar 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}U, ^{232}Th and ^{40}K was calculated using the following formula [16]

$$\text{AGDE}\ (\mu\text{Sv y}^{-1}) = 3.09A_U + 4.18A_{Th} + 0.314A_K \qquad (3)$$

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 radiations are negligible. The obtained value of AGDE for the studied samples ranges from 294.34 to 948.10 with an average of 621.39 μSv y^{-1}. In literature, the world average value for AGDE was found to be 300 μSv 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]

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \qquad (4)$$

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 0.326×10^{-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}) [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.

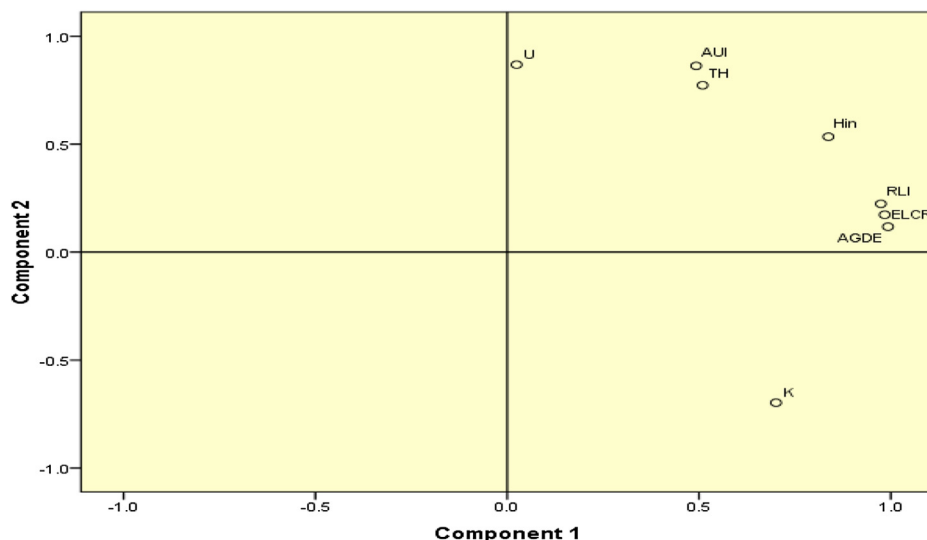| Variables	Component	
	1	2
238-U	0.024	0.868
232-Th	0.509	0.773
40-K	0.701	−0.698
RLI	0.974	0.223
AUI	0.493	0.863
AGDE	0.993	0.117
ELCR	0.984	0.273
H_{in}	0.837	0.534
% of Variance explained	57.47	37.00

Fig. 6 – Graphical representation of component 1 (57.47%) and component 2 (37%).

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].

$$H_{in} = \frac{A_U}{185 \text{ Bq/kg}} + \frac{A_{Th}}{259 \text{ Bq/kg}} + \frac{A_K}{4810 \text{ Bq/kg}} \quad (5)$$

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
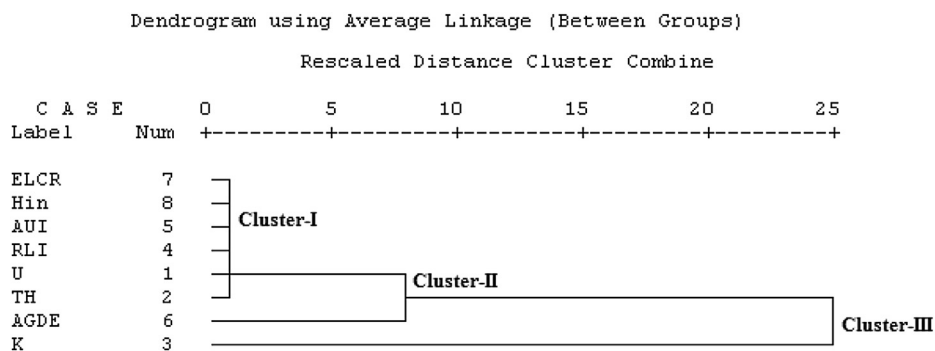

Fig. 7 – Dendrogram shows cluster of radionuclides and their radiological parameters.

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	Adiyaman 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	Meatokanivoor	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

[25]. 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_{in}) 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
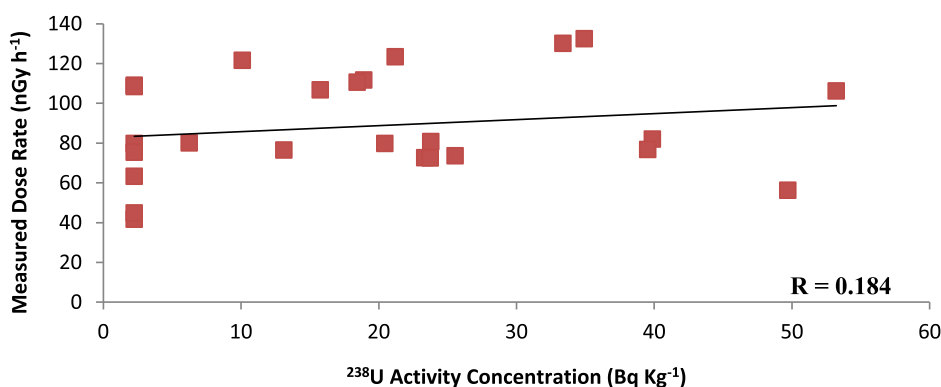

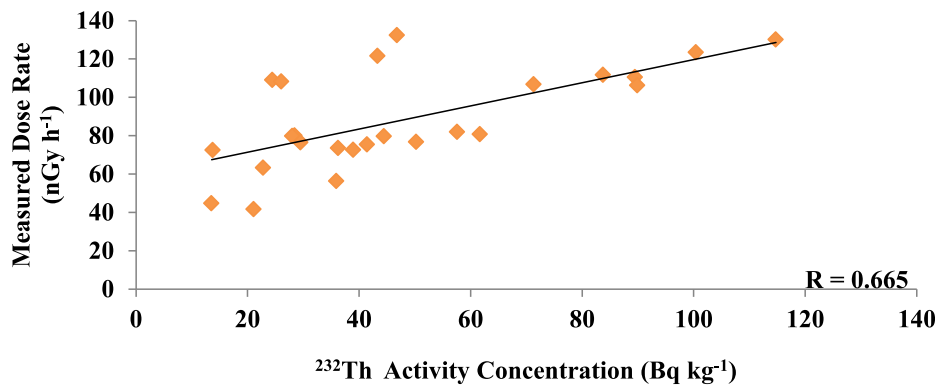**Fig. 8 – Scatter plot of the ^{238}U versus measured dose rate.**

Fig. 9 – Scatter plot of the ^{232}Th 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}Th and ^{40}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}U and ^{232}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}U and ^{232}Th and ^{238}U and ^{40}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}Th (0.665) and ^{40}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}Th and ^{40}K series, a poor correlation existed between ^{238}U (0.184) with the measured dose rate as
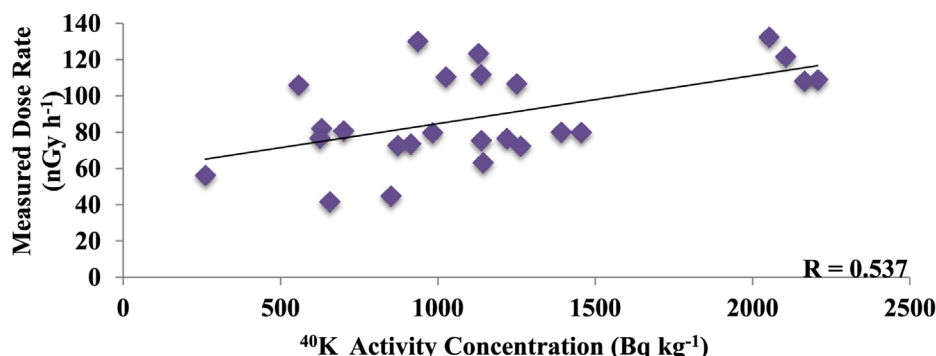

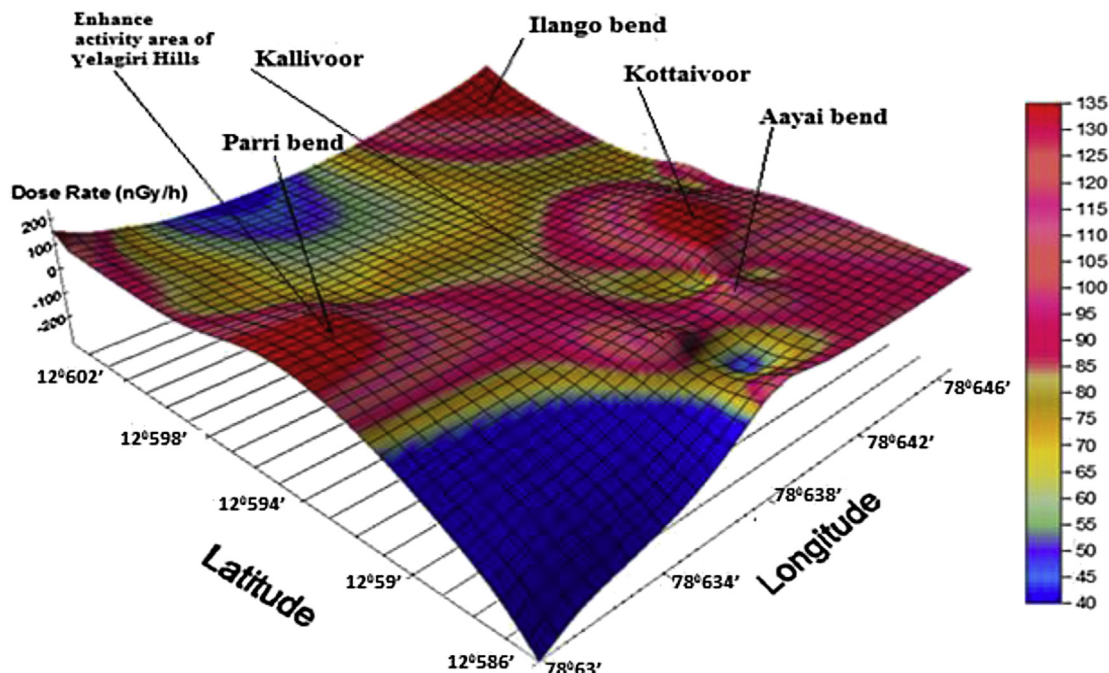**Fig. 10 – Scatter plot of the ^{40}K versus measured dose rate.**

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

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 (0.700×10^{-3}) of ELCR is more twice than the world average value average (0.290×10^{-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.

REFERENCES

[1] Tzortzis M, Svoukis E, Tsetos H. A comprehensive study of natural gamma radioactivity levels and associated dose rates from surface soils in Cyprus. Radiat Prot Dosim 2004;109(3):217–24.

[2] Abbady A, Ahmed NK, El-Arabi AM, Michel R, El-Kamel AH, Abbady AGE. Estimation of radiation hazard indices from natural radioactivity of some rocks. Nucl Sci Tech 2006;17(2):118–22.

[3] El-Arabi AM, Ahmed NK, El-Kamel AH. Gamma spectroscopic analysis of powdered granite samples in some Eastern desert's areas. In: Proceedings of the fifth radiation conference, 5–9 November 2000, Cairo, Egypt; 2000.

[4] Ravisankar R, Chandrasekaran A, Vijayagopal P, Venkatraman B, Senthilkumar G, Eswaran P, et al. Natural radioactivity in soil samples of Yelagiri Hills, Tamil Nadu, India and the associated radiation hazards. Radiat Phys Chem 2012;81:1789–95.

[5] Sartandel SJ, Jha SK, Bara SV, Tripathi RM, Puranik VD. Spatial distribution of uranium and thorium in the surface soil around proposed uranium mining site at Lambapur and its vertical profile in the Nagarjuna Sagar Dam. J Environ Radioact 2009;100:831–4.

[6] Ravisankar R, Rajalakshmi A, Eswaran P, Gajendrian V, Meenakshisundram V. Radioactivity levels in soils of salt field area Kelambakkam, Tamil Nadu, India. Nucl Sci Tech 2007;18:372–5.

[7] UNSCEAR – United National Scientific Committee on the Effects of Atomic Radiation. Sources and risks of ionizing radiation [Report to the general assembly with annexes]. New York: United Nations; 2000.

[8] Ziqiang P, Yang Y, Mingqiang G. Natural radiation and radioactivity in China. Radiat Prot Dosim 1988;24(1/4):29–38.

[9] NEA-OECD. Exposure to radiation from natural radioactivity in building materials [Report by NEA group of Experts of the nuclear energy agency]. Paris, France: OECD; 1979.

[10] Chowdhury MI, Kamal M, Alam MN, Saleha Yeasmin, Mostafa MN. Distribution of naturally occurring radionuclides in soils of the southern districts of Bangladesh. Radiat Prot Dosim 2005;335:1–5.

[11] Abbady AGE. Estimation of radiation hazard indices from sedimentary rocks in Upper Egypt. Appl Radiat Isot 2004;60:111–4.

[12] Alam MN, Miah MMH, Chowdhury MI, Kamal M, Ghose S, Islam MN, et al. Radiation dose estimation from the radioactivity analysis of lime and cement used in Bangladesh. J Environ Radioact 1999;42:77–85.

[13] Ramasamy V, Suresh G, Meenakshisundaram V, Ponnusam. V. Horizontal and vertical characterization of radionuclides and minerals in river sediments. Appl Radiat Isot 2011;69:184–95.

[14] El-Gamal A, Nasr S, El-Taher A. Study of the spatial distribution of natural radioactivity in Upper Egypt Nile River sediments. Radiat Meas 2007;42:457–65.

[15] UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, effects and risks of ionizing radiation. New York: United Nations; 1988.

[16] Mamont-Ciesla K, Gwiazdowski B, Biernacka M, Zak A. Radioactivity of building materials in Poland. In: Vohra G, Pillai KC, Sadavisan S, editors. Natural radiation environment. New York: Halsted Press; 1982. p. 551.

[17] Xinwei L, Lingqing W, Xiaodan J. Radiometric analysis of Chinese commercial granites. J Radioanal Nucl Chem 2006;267(3):669–73.

[18] Taskin H, Karavus M, Ay P, Topuzoglu A, Hidiroglu S, Karahan G. Radionuclide concentrations in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey. J Environ Radioact 2009;100:49–53.

[19] Al-Trabulsy HA, Khater AEM, Habbani FI. Radioactivity levels and radiological hazard indices at the Saudi coastline of the Gulf of Aqaba. Radiat Phys Chem 2011;80:343–8.

[20] Ashley RP, Lloyd JW. An example of the use of factor analysis and cluster analysis in groundwater chemistry interpretation. J Hydrol 1978;39:335–64.

[21] Jackson JE. A user's guide to principal components. New York: Wiley; 1991.

[22] Meglen RR. Examining large databases: a chemometric approach using principal component analysis. Mar Chem 1992;39:217–37.

[23] Laaksoharju M, Skarman C, Skarman E. Multivariate mixing and mass balance (M3) calculations, a new tool for decoding hydrogeochemical information. Appl Geochem 1999;14:861–71.

[24] Wenning RJ, Erickson GA. Interpretation and analysis of complex environmental data using chemometric methods. Trends Anal Chem 1994;13:446–57.

[25] Liu WX, Li XD, Shen ZG, Wang DC, Wai OWH, Li YS. Multivariate statistical study of heavy metal enrichment in sediments of the Pearl River Estuary. Environ Pollut 2003;121:377–88.

[26] Tanaskovi Irena, Golobocanin Dusan, Milijevic Nada. Multivariate statistical analysis of hydrochemical and radiological data of Serbian spa waters. J Geochem Explor 2012;112:226–34.

[27] Adams JAS. In: Israel H, Krebs A, editors. Nuclear radiation in geophysics. Berlin: Springer-Verlag; 1962.

[28] Mishra UC, Sadasivan S. Natural radioactivity levels in Indian soils. J Sci Ind Res 1971;30(2):59–62.

[29] Mandakini M, Narayani K, Sengupta D. Spatial distribution of gamma radiation levels in surface soils from Jaduguda uranium mineralization zone, Jharkhand, India, using gamma ray spectrometry and determination of outdoor dose to the population. J Med Phys 2010;35(4):235–41.

[30] Agbalagba E, Onoja R. Evaluation of natural radioactivity in soil, sediment and water samples of Niger Delta (Biseni) flood plain lakes, Nigeria. J Environ Radioact 2011;102:667–71.

[31] Almayahi CBA, Tajuddin AA, Jaafar MS. Radiation hazard indices of soil and water samples in Northern Malaysian Peninsula. Appl Radiat Isot 2012;70:2652–60.