Short Communication

# Application of multivariate technique to evaluate spatial distribution of natural radionuclides along Tamil Nadu coastline, east coast of India

Satyanarayan Bramha[1] · Sunil Kumar Sahoo[2] · Venkatesan Subramanian[1] · Balasubramanian Venkatraman[1] · Prasanta Rath[3]



**Abstract**

The study focuses on the spatial mapping of naturally occurring radionuclides along entire Tamil Nadu coast, which constitute nearly 30% of the east coast of India. In view of this, a total of 37 beach sediment samples are collected, and spectral measurement was carried out by High Purity Germanium detector. The average activity concentrations were found to be in the range of 34.33 ± 32.94 Bq kg$^{-1}$ for $^{238}$U, 51.55 ± 40.39 Bq kg$^{-1}$ for $^{238}$Th and 282.59 ± 84.45 Bq kg$^{-1}$ for $^{40}$K. The contour maps showed the spatial distributions of each radionuclide and were drawn using the kriging method. Box-whisker plot shows the variation of activity concentrations of radionuclides, which follows the order $^{40}$K > $^{232}$Th > $^{238}$U in all the sediment samples. To understand the complex relationships among the radioactive variables and its environmental classifications, a multivariate statistical technique such as correlation matrices, and cluster analysis were applied to the radioactive data sets.

**Keywords** Spatial distribution · Multivariate technique · Natural radioactivity · TN coastline · East coast of India

## 1 Introduction

Coastal sediments are weathering resistant residues of geological formations, transported to the coast by natural phenomena such as wind, river, and glaciers, and are deposited on the beaches by the coastal process [25, 66]. The naturally occurring radionuclides like $^{238}$U, $^{232}$Th, and $^{40}$K, and their varying concentrations in soil and sediment depend upon the local geology of each region in the world [21]. These primordial radionuclides and their daughter products are gamma emitters, which are the main contributors to background radiation. As per the survey, 87% of the dose received by human beings is due to natural radiation sources [32]. The study on distribution of the natural radionuclides is quite helpful in understanding about dredging dispersal, accumulation rate, sediment logical composition, and also the relation between grain size and density of the sediments [24, 36, 52, 53, 67]. In addition to this, it plays a major role in the adsorption studies with mineralogical, geochemical, and physicochemical parameters [11, 20].

Human beings are constantly exposed to background radiation due to natural radioactivity, which are coming from the different rocks, sand and cosmic rays. The average dose received from background radiation is around 2.4 mSv y$^{-1}$, which can vary depending on the geology and altitude. Peoples are living safely with a wide range of dose (1–50 mSv y$^{-1}$) from background radiation. The average background radiation level in Kerala, India, is about 12.5 mSv y$^{-1}$ due to the monazite sand deposit in the beach. Comparable levels occur in Brazil and Sudan, with average exposures up to about 40 mSv y$^{-1}$ to many

✉ Prasanta Rath, pr_kiit@yahoo.co.in | [1]Radiological and Environmental Safety Division, Health, Safety and Environment Group, Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, India. [2]Environmental Assessment Division, Bhabha Atomic Research Centre, Trombay, Mumbai, India. [3]Present Address: Department of Chemistry, School of Applied Sciences, KIIT University, Bhubaneswar, Odisha 751024, India.

SN Applied Sciences (2019) 1:689 | https://doi.org/10.1007/s42452-019-0716-9

Received: 30 December 2018 / Accepted: 4 June 2019 / Published online: 10 June 2019

people. Taking the individual average dose of 2 mSv $y^{-1}$, someone who lived to the age of 80 years would have accumulated 160 mSv of radiation from natural sources during their lifetime [60].

Radiological investigations have been carried out by many authors in small stretches along Tamil Nadu (TN) coast [4, 9, 15, 23, 30, 31, 45, 51, 55, 57], as per their specific mandate. In order to have the background data for the entire TN coastline, the current study carried out. This study focused on mapping of the spatial distribution of Naturally Occurring Radioactive Materials (NORMs) such as $^{238}$U, $^{232}$Th, $^{40}$K and their radiological parameters throughout TN coastline, east coast of India, which may serve as baseline and background data for the entire coast. This study also used a multivariate statistical technique to the spatial data set for understanding the distribution pattern of radionuclides and their association with the geological characteristics.

## 2 Materials and methods

### 2.1 Study area and sample collection

The study area covers entire TN coastline of 1076 km from Palar of Tiruvallur (longitude: 80.31849501(E) Latitude: 13.56020134 (N)) to Thoothoor of Kanyakumari (Longitude: 76.93527495(E) Latitude: 8.213782474 (N)) districts. The study area is almost like a flat terrain with a gentle slope towards the Bay of Bengal and characterized by alluvial and coastal deltaic plain sediments [33].

Details of samples collected (TN: 01 to 37) with their locations were depicted in Fig. 1. Total of 37 sediment samples (each of about 1 kg) collected from the upper few centimeters of the surface layer in between high tide and low tide line, as per the Guideline of International Atomic Energy Agency (IAEA) Trs No 295 [26] in polypropylene bags were taken immediately to the laboratory. After removing the stones, pebbles, the samples were mixed thoroughly for homogenization and sieved though < 1 mm mesh sieve (ASTM Standard C 1402-04). The samples were dried in an oven at 110 °C for 24 h until their weight became constant [12]. The dried samples were packed in pre-weighed cylindrical (250 ml capacity) plastic containers. The net weight of the samples was noted. The containers were closed, sealed to prevent the escape of gaseous radioactive daughter products and stored for more than 40 days to achieve secular equilibrium between $^{222}$Rn and $^{226}$Ra [5, 14, 49].

### 2.2 Gamma ray spectrometric analysis

All the samples were analyzed using High Purity Germanium (HPGe) detector of 30% relative efficiency and energy resolution of 1.85 keV at 1332.51 keV. Computerized HPGe detector consists of vertical dipstick geometry detector, having a spectroscopy amplifier and a multichannel analyzer. Lead shielding of 10-cm thickness cover to the detector to reduce the background activities and cooling facility through liquid nitrogen. The certified reference materials sources from IAEA are RGU (Radiometric Reference for Uranium), RGTh (Radiometric Reference for Thorium) and RGK (Radiometric Reference for Potassium) were used for efficiency calculations [14]. The activity contents of the standards in 250 ml geometry are estimated within ± 3% accuracy. The sample spectrum and background spectrum were acquired for 10,000 s [37]. The gamma-ray photo peaks at 1460 keV ($^{40}$K), 1764 keV ($^{214}$Bi) and 2614 keV ($^{232}$Th) were used for the estimation of activities of $^{40}$K, $^{238}$U, and $^{232}$Th in samples. The minimum detection limit (MDL) for $^{238}$U, $^{232}$Th, and $^{40}$K was found to be 8.3, 4.6 and 19 Bq/kg respectively for a counting period of 10,000 s.

### 2.3 Spatial interpolation technique

Contouring is a way to visualize the proper spatial distribution of a variable concerning its position [35]. In spite of the availability of many interpolation techniques for plotting contouring map. In this paper, the kriging method used for gridding the data, which is one of the most flexible and accurate technology. Kriging produce visually attractive maps and useful in identifying a trend from irregularly spaced data [14, 37, 61]. This is also an exact or smooth interpolator depending on the user-specific parameter. It incorporates anisotropy and underlying trends efficiently and naturally.

### 2.4 Statistical analysis

Various multivariate statistical techniques have been used on collected data set from sediment samples, to formulate classifications of environmental variables without losing much information and it is an efficient tool to display complicated relationship among many variables [1, 14, 39]. The data sets of 111 observations including activity concentrations of $^{232}$U, $^{238}$Th, and $^{40}$K as well as their radiological parameters were processed for multivariate statistical analysis, such as Correlation Matric (CM), and Cluster Analysis (CA) [3, 4, 29, 53, 59]

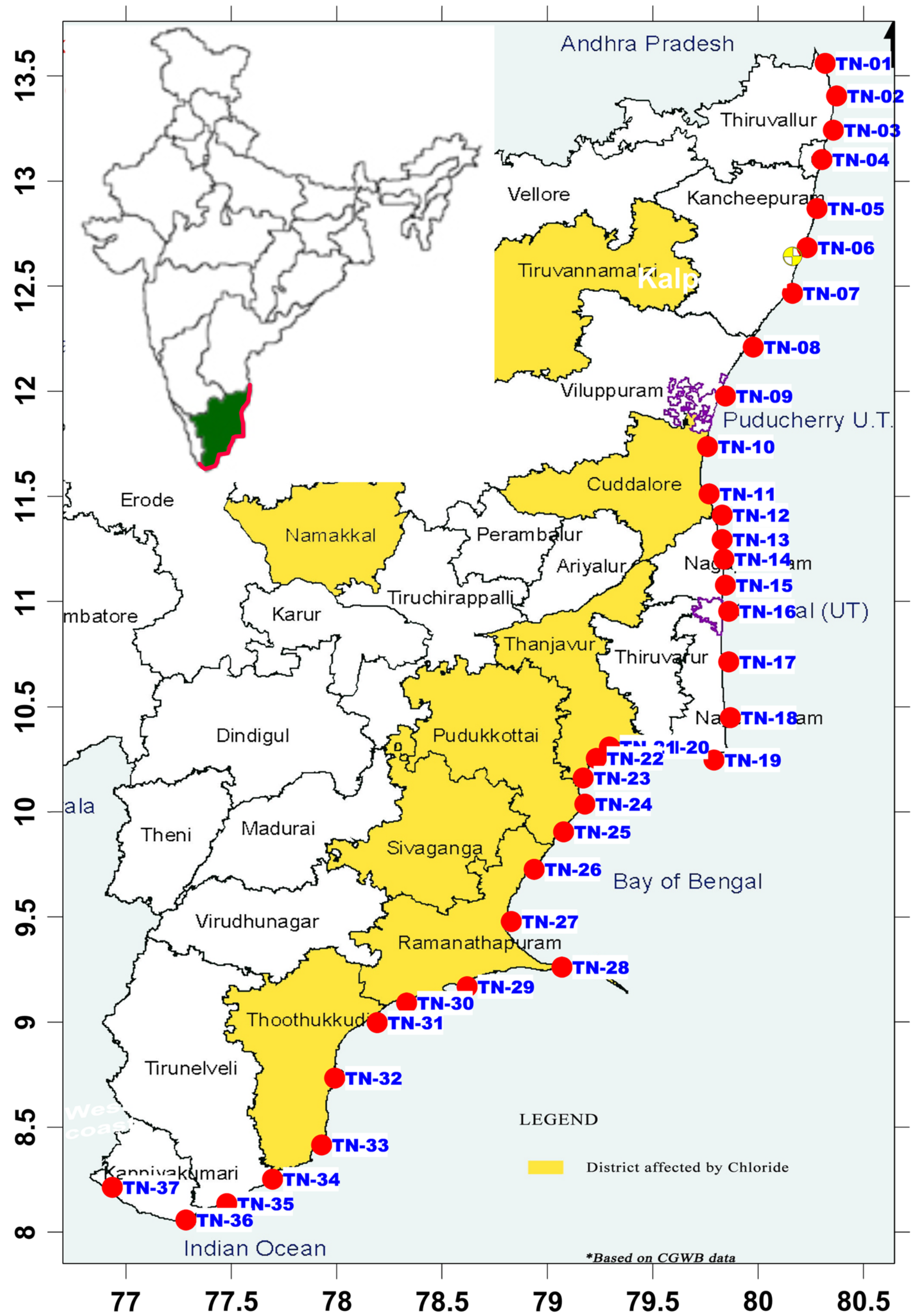


**Fig. 1** Map showing TN coastline with station locations

using statistical software "Statistical Programme for Social Science" SPSS 19.0.

## 3 Result and discussions

### 3.1 Spatial distribution

The contour map shows the distribution of the radionuclide's activity concentrations in the sediment samples analyzed. Golden software surfer 13.0 with the kriging method was applied for spatial interpolation and gridding the data [37, 38]. The distribution graph of activity concentration of radionuclides is shown in Fig. 2. The radiological indices such as Radium equivalent activity ($Ra_{eq}$), Absorbed gamma dose rate (DR), Annual Gonadal Dose Equivalent (AGDE), Annual effective dose rate (HR), Activity utilization index (AUI), external hazard index ($H_{ex}$), internal hazard index ($H_{in}$), and Gamma radiation representative level index (RLI) were calculated as per [6, 13, 16, 18, 34, 46, 62, 63, 68].

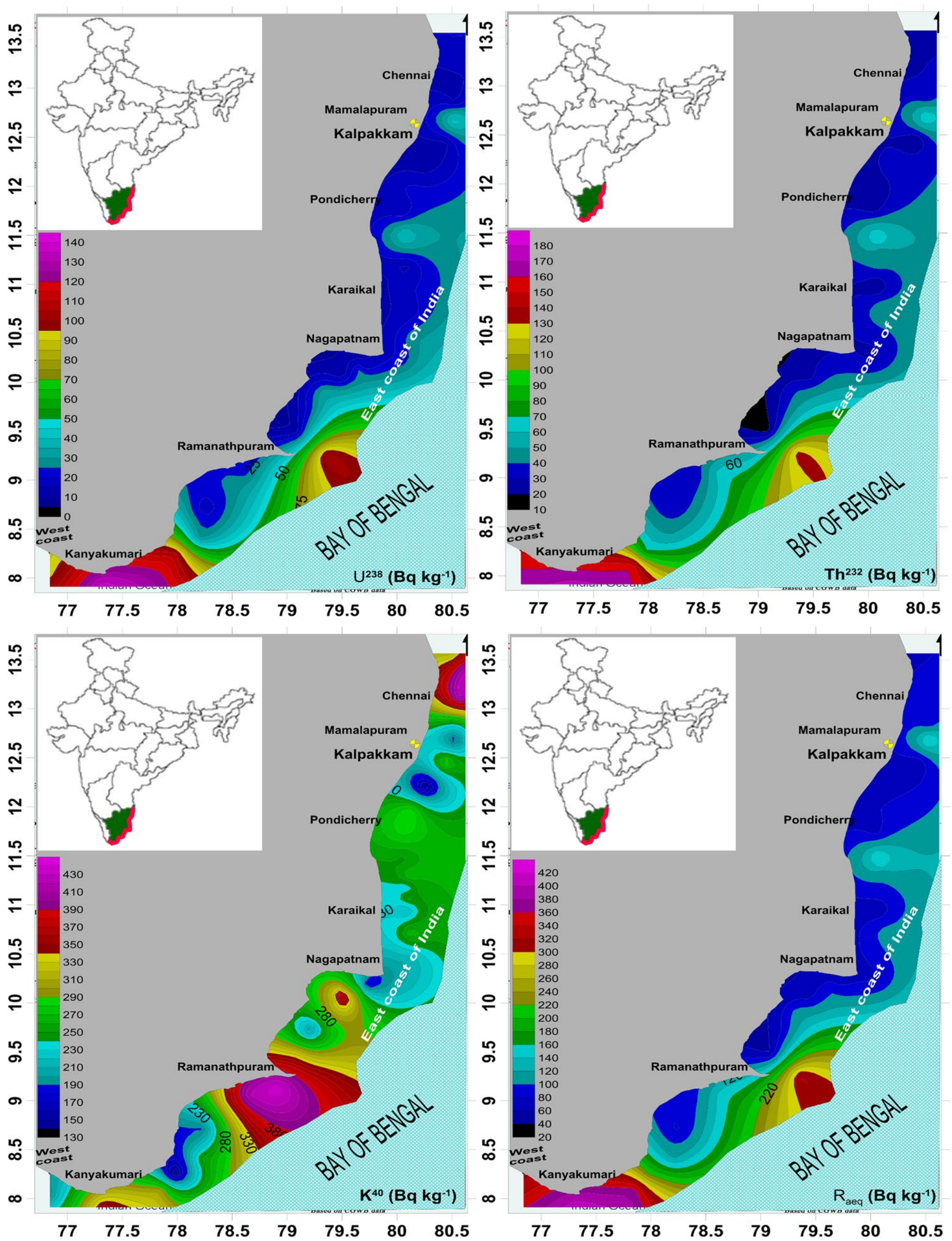


**Fig. 2** Spatial distribution of the $^{238}$U, $^{232}$Th, and $^{40}$K activity concentrations (Bq kg$^{-1}$) of the sediment from TN coast, East Coast of India

The distribution of average activity concentration of $^{238}$U (12.15-138.56) was 34.33 ± 32.94 Bq kg$^{-1}$. It has been found that 16% of the samples are higher than the World average of 40 Bq kg$^{-1}$, and 19% of the samples are higher than the Indian average of 30 Bq kg$^{-1}$. The average activity concentration of $^{238}$Th (15.08- 173.03) was 51.55 ± 40.39 Bq kg$^{-1}$, where, 27% of the samples were having higher than the world average of 45 Bq kg$^{-1}$, whereas 19% of the samples remained higher than Indian average of 65 Bq kg$^{-1}$. The average distribution of the activity concentrations of the $^{40}$K (131.56–438.20) was 282.59 ± 84.45 Bq kg$^{-1}$ and showed 6% of the samples are higher than the world average of 420 Bq kg$^{-1}$, whereas 16% of the samples remained higher than Indian average of 400 Bq kg$^{-1}$. The activity concentrations of $^{238}$U and $^{232}$Th were relatively high at Kanyakumari coastline, the southern part of TN coast, which could be due to the presence of ilmenite and monazite in the beach and also the presence of granite and granitoid rocks [2, 10]. On the other hand, the $^{40}$K activity concentration was relatively high in northern part of the TN coastline and also in Rameswaram coastline, which could be attributed the presence of light minerals and dead shells, mica, and feldspar in the sediment of coastal area [17, 40, 44]. The $Ra_{eq}$ concentrations in the southern part of the TN coast were high, which might be mainly due to high activity

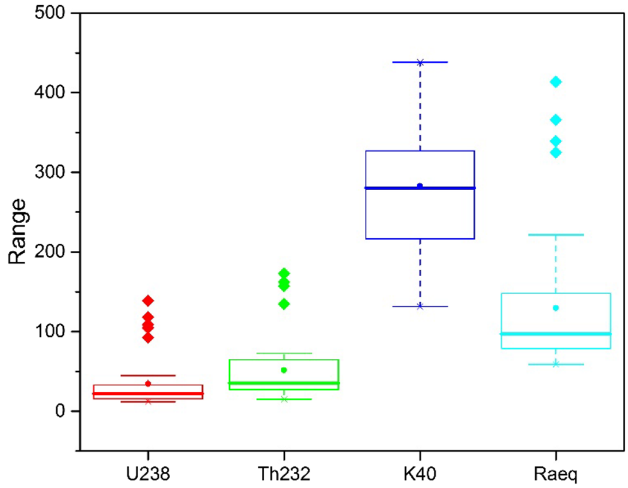


**Fig. 3** Box-Whisker plot of the activity concentration of radionuclides in sediment samples (here the minimum and maximum limits, the middle point is median, and the x marks are the outliers of the radionuclide activity concentrations)

concentrations of $^{238}U$ and $^{232}Th$. The distribution of activity concentrations is shown in Fig. 3. The wide range of variation is mainly due to the coastal morphological, lithological, and geological nature of the coastline [7, 8, 28]. In all the samples, the activities concentration was in the order $^{40}K > ^{232}Th > ^{238}U$ and $^{40}K$ largely dominated the total activity, which might be due to the greater abundance of the particular element in the earth crust and also in the sediments of TN coast [42].

The Box-whisker graph of the activity concentrations of the radionuclides in the TN coastline shown in Fig. 3. From the figure, it observed that the activity concentration of $^{40}K$ varied widely as compared with the other two radionuclides, whereas activity concentrations of $^{232}Th$ varied slightly higher than $^{238}U$. It could be due to the presence of placer deposits monazite in the sediments of the TN coastline [41, 50, 53].

From the comparison Table 1, the $^{238}U$ activity was low compared with previous studies by Kannan et al. [30], SureshGandhi et al. [59] and Ajithra and Shanthi [3], whereas the $^{232}Th$ activity was high from the previous studies by Bukhari [15], Ramasamy et al. [47], Sivakumar et al. [54] and Ravisankar et al. [48]. But the present study $^{40}K$ activity observed high from the previous studies by Punniyakotti and Ponnusamy [41], Raja [43], Bukhari [15], Ramasamy et al. [47] and Ajithra and Shanthi [3].

$Ra_{eq}$ values varied from 58.88 to 413.57, with an average 129.81 Bq kg$^{-1}$. As compare with NEA-OECD (1979), the present $Ra_{eq}$ values do not exceed the admissible limit of 370 Bq kg$^{-1}$. So, it does not pose any negative radiological impact. $D_R$ value ranged in between 53.91 and 346.46 with an average value of 110.90 nGy h$^{-1}$. Slightly higher $D_R$ value noticed as compared with the world average value of 84 nGy h$^{-1}$ UNSCEAR [62], which may be due to more contribution of $^{232}Th$ activity in the study area. AEDE ranged in between 0.07 and 0.43 with an average value of 0.14 mSv y$^{-1}$. As per UNSCEAR [63], the average AEDE for terrestrial radionuclides is 0.46 mSv y$^{-1}$, whereas, the present study area, the average value is 0.14 mSv y$^{-1}$,

**Table 1** Comparison of activity concentrations of present work with previous researchers of TN coastline, world, and India average

| S/N. | Study area in TN coast | Activity concentration (Bq kg$^{-1}$) | | | References |
|---|---|---|---|---|---|
| | | $^{238}U$ | $^{232}Th$ | $^{40}K$ | |
| *Tamil Nadu* | | | | | |
| 01 | South east coast | 8.77 | 76.48 | 202.87 | Punniyakotti and Ponnusamy [41] |
| 02 | Gulf of mannar | 415 | 1372 | 541 | Somasundaram [56] |
| 03 | Kalpakkam Coast | 124 | 1613 | 358 | Kannan et al. [30] |
| 04 | Pichavaram | 25.9 | 65.1 | 190 | Raja [43] |
| 05 | Palk strait | 14.2 | 46.4 | 233.9 | Bukhari [15] |
| 06 | North east coast | 8.4 | 24.5 | 274.8 | Ramasamy et al. [47] |
| 07 | South west coast | 18.4 | 56.5 | 285 | Satheeshkumar et al. [51] |
| 08 | North coast of Chennai | 8.6 | 108 | 372 | Inigo Valan et al. [27] |
| 09 | Thazhankuda to Kodiyakkarai coast | 3.67 | 37.23 | 387.17 | Sivakumar et al. [54] |
| 10 | Pattipulam to Devanampattinam coast | BDL | 14.29 | 360.23 | Ravisankar et al. [48] |
| 11 | North east coast of Tamilnadu | 35.12 | 713.16 | 349.60 | SureshGandhi et al. [59] |
| 12 | Kanyakumari district, TN coast | 62.90 | 279.53 | 108.35 | Ajithra and Shanthi [3] |
| 13 | India | 29 | 64 | 400 | UNSCEAR [64] |
| 14 | Worldwide | 35 | 30 | 400 | UNSCEAR [62] |
| *Present study* | | | | | |
| 13 | Entire TN coastline, East coast of India | 34.3 | 51.6 | 282.6 | Present study |

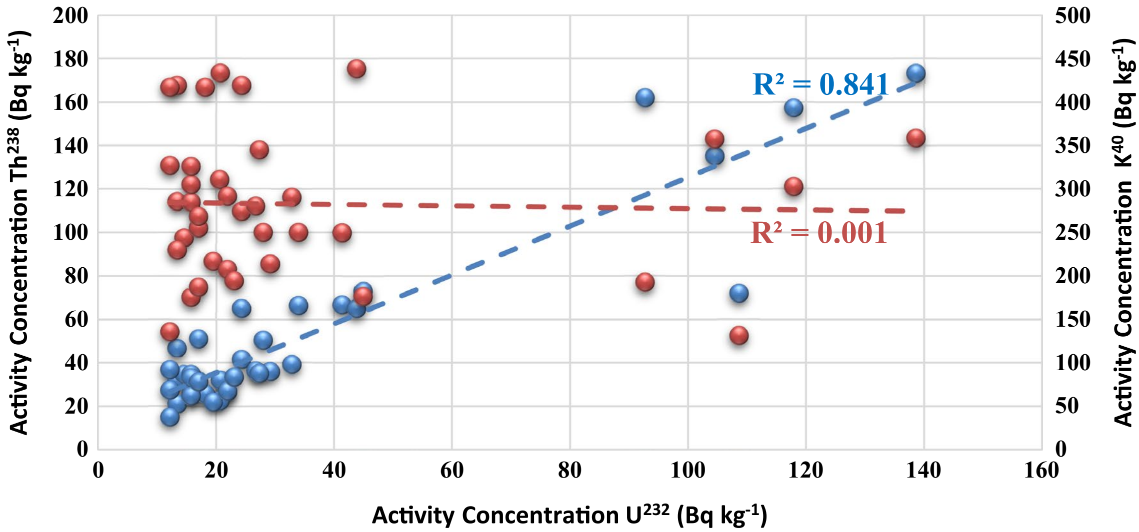


**Fig. 4** Scatter plot showing the correlation among $^{238}U$ with $^{232}Th$ and $^{238}U$ and $^{40}K$, in blue and red colour dots respectively, and also with $R^2$ value

which is less than the average world value. So, it satisfies the standards for radiation safety norms. $H_{in}$ value ranged in between 0.19 and 1.49 with an average of 0.44 whereas, $H_{ex}$ values ranged from 0.16 to 1.12 with an average of 0.35. It observed that both $H_{in}$ and $H_{ex}$ values are less than the permissible limit (< 1) as per UNSCEAR [64], which indicates, the study area does not possess any radiological health risk to the people living in nearby.

## 3.2 Multivariate statistical techniques

### 3.2.1 Pearson's correlation coefficient analysis

Pearson correlation analysis has been carried out to determine the inter associations and strength of association among radionuclides and radiological parameters. The results of the Pearson correlation coefficient of variables are given in Fig. 4. A very strong positive correlation ($R^2$= 0.841) noticed between the $^{238}U$ and $^{232}Th$. Which indicates a strong relationship between $^{238}U$ and $^{232}Th$ decay series in sediment which occur together in nature [1]. A weak correlation ($R^2$= 0.001) observed between $^{40}K$ and uranium/thorium, indicating its origin from a different decay series in nature. The calculated radiological parameters $Ra_{eq}$, DR, $H_{in}$, $H_{ex}$, showed a strong positive correlation with $^{238}U$ and $^{232}Th$. It indicates that all these parameters are strongly associated with the activity of $^{238}U$ and $^{232}Th$ in the soils, and these radionuclides primarily contribute to the emission of gamma radiation in the study area. The results of the present study are also supported by previous studies [3, 53, 54, 59].

### 3.2.2 Cluster analysis

Cluster analysis (CA) for classifies a set of data into two or more mutually exclusive un-known groups, called clusters based on their nearness and similar nature [65]. It discovers a system of organized variable data set, into clusters, in which the members of the common share having similar properties and characters [58]. Cluster analysis is a suitable semi-quantitative practice for analyzing the data and determining the linkages [53]. In the present work, CA performed as hierarchical clustering using Ward's method to calculate the Euclidean distance between variables. Figure 5 shows the results of CA as a dendrogram, which was carried out by using (a) ten variables, including activity concentrations as well as radiological indices and (b) 37 variables of all sample locations. All the variables get grouped into two major statistically significant clusters. In Fig. 5a, Cluster I is associated with $^{238}U$, $^{232}Th$, and other radiological indices, whereas, cluster II is associated with $^{40}K$. All of the natural radionuclides were represented as one group, i.e. cluster I with similar characteristics as they originate from $^{232}Th$ and $^{238}U$ series. $^{40}K$ identified in another group far from the other radioisotopes and grouped closely with the group of grain size distribution. The close relation between $^{238}U$ and $^{232}Th$ series members but not with $^{40}K$ was in accordance with the results described by several others [19, 22]. In Fig. 5b, Cluster I is associated with locations 28, 35, 36, and 37, whereas, cluster II is associated other 33 locations. From this, it supports the spatial distribution with high activity concentration in the southern part (cluster 1) of TN coast as compared with northern (cluster 2).

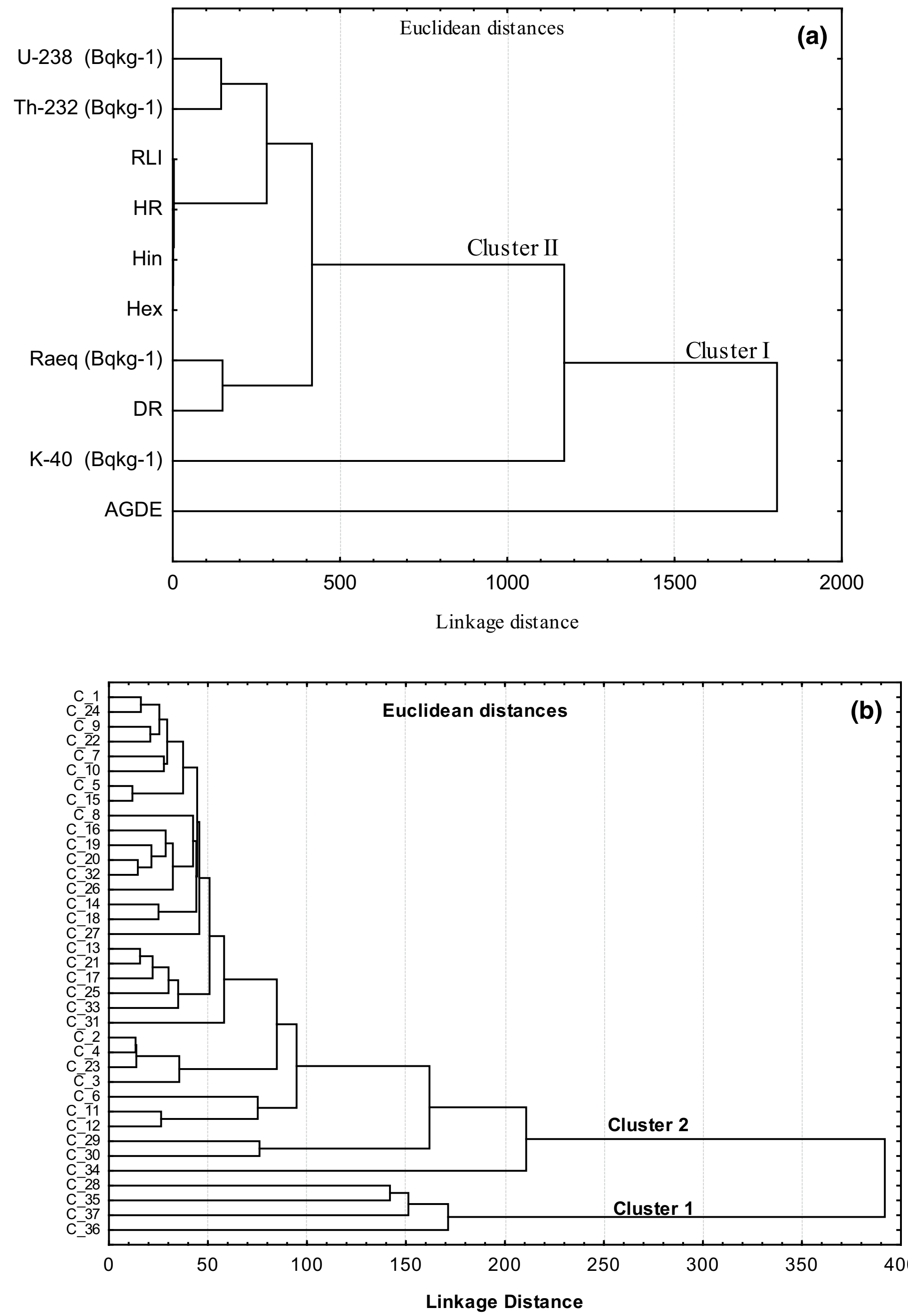


**Fig. 5** Hierarchical clustering dendrogram **a** parameter wise and **b** station wise by complete linkage method for coastal sediment samples

## 4 Conclusion

The study covers the entire coastline of Tamil Nadu, and the data generated will act as the baseline for background radiation level for the entire TN coast. The contour map shows the spatial distribution of activity concentrations of each radionuclide along the coastline. The activity concentration of the $^{40}K$ dominated in the study area as compared with $^{232}Th$ and $^{238}U$, which might occur due to the greater abundance of potassium in the earth crust. The activity concentrations of radionuclides in most of the sediment samples remained below the world as well as the India average values as per UNSCEAR, which indicates that TN coastline is safe and does not possess any harmful radiological effect to the peoples living around it. The calculated radiological parameters $Ra_{eq}$, DR, $H_{in}$, $H_{ex}$ showed that very strong positive correlation with $^{238}U$ and $^{232}Th$, which indicates that the above parameters are strongly associated with the activity of $^{238}U$ and $^{232}Th$ in the sediment.

## Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

## References


1. Adam-Guillermin C, Pereira S, Della-Vedova C, et al (2012) Genotoxic and reprotoxic effects of tritium and external gamma irradiation on aquatic animals. In: Reviews of environmental contamination and toxicology, pp 67–103
2. Ahmed NK, Abbady A, El Arabi AM et al (2006) Comparative study of the natural radioactivity of some selected rocks from Egypt and Germany. Indian J Pure Appl Phys 44:209–215
3. Ajithra A, Shanthi G (2016) Assessment of Beach sand using Gamma Ray Spectrometer in Thiruvanathapuram District, Kerala of South India. IRA-Int J Technol Eng 5:56. https://doi.org/10.21013/jte.v5.n3.p2
4. Ajithra A, Venkatraman B, Jose M et al (2017) Assessment of natural radioactivity and associated radiation indices in soil samples from the high background radiation area, Kanyakumari district, Tamil Nadu, India. Radiat Prot Environ 40:27. https://doi.org/10.4103/rpe.rpe_31_16
5. Akhtar N, Tufail M, Ashraf M, Mohsin Iqbal M (2005) Measurement of environmental radioactivity for estimation of radiation exposure from saline soil of Lahore, Pakistan. Radiat Meas 39:11–14. https://doi.org/10.1016/j.radmeas.2004.02.016
6. Alam MN, Chowdhury MI, Kamal M et al (1999) Radiological assessment of drinking water of the Chittagong region of Bangladesh. Radiat Prot Dosimetry 82:207–214. https://doi.org/10.1093/oxfordjournals.rpd.a032626
7. Baeza A, Del Rio M, Miro C, Paniagua JM (1992) Natural radioactivity in soils of the province of Caceres (Spain). Radiat Prot Dosimetry 45:261–263
8. Baeza A, Del Rio M, Miro C, Paniagua J (1994) Natural radionuclide distribution in soils of Cáceres (Spain): dosimetry implications. J Environ Radioact 23:19–37. https://doi.org/10.1016/0265-931X(94)90503-7
9. Bala Sundar S, Chitra N, Vijayalakshmi I et al (2015) Soil radioactivity measurements and estimation of radon/thoron exhalation rate in soil samples from Kalpakkam residential complex. Radiat Prot Dosimetry 164:569–574. https://doi.org/10.1093/rpd/ncv313
10. Bara SV, Arora V, Chinnaesakki S et al (2012) Radiological assessment of natural and fallout radioactivity in the soil of Chamba and Dharamshala areas of Himachal Pradesh, India. J Radioanal Nucl Chem 291:769–776. https://doi.org/10.1007/s10967-011-1349-7
11. Belivermis M, Kiliç Ö, Çotuk Y, Topcuoğlu S (2010) The effects of physicochemical properties on gamma emitting natural radionuclide levels in the soil profile of Istanbul. Environ Monit Assess 163:15–26. https://doi.org/10.1007/s10661-009-0812-1
12. Benke RR, Kearfott KJ (1999) Soil sample moisture content as a function of time during oven drying for gamma-ray spectroscopic measurements. Nucl Instru Methods Phys Res Sect A Accel Spectrom Detect Assoc Equip 422:817–819. https://doi.org/10.1016/S0168-9002(98)01004-3
13. Beretka J, Mathew PJ (1985) Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys 48:87–95. https://doi.org/10.1097/00004032-198501000-00007
14. Bramha SN, Krishnan H, Subramanian V et al (2018) Baseline evaluation study of naturally occurring radionuclides in soil samples from vicinity of India's First Fast Reactor Fuel Cycle Facility (FRFCF), Dae Complex, Kalpakkam. India. Radiat Prot Dosimetry 1:1. https://doi.org/10.1093/rpd/ncy262
15. Bukhari S (2004) Studies on the bioaccumulation of natural radionuclides in the seafood organisms and dose transfer to the coastal population of Palk Strait, South East Coast of India. Ph.D. Thesis. Tiruchirappalli: Bharathidasan University
16. Bushong SC (1983) Ionizing radiation: sources and biological effects by United Nations Scientific Committee on the effects of atomic radiation. Med Phys 10:920. https://doi.org/10.1118/1.595436
17. Carvalho FP, Oliveira JM, Malta M (2011) Radionuclides in plants growing on sludge and water from uranium mine water treatment. Ecol Eng 37:1058–1063. https://doi.org/10.1016/j.ecoleng.2010.07.011
18. Charles M (2010) Effects of ionizing radiation: United Nations Scientific Committee on the effects of atomic radiation: UNSCEAR 2006 Report, Volume 1–Report to the General Assembly, with Scientific Annexes A and B. Radiat Prot Dosimetry 138:187–189. https://doi.org/10.1093/rpd/ncp262
19. Chen R-H, Lee C-H, Chen C-S (2001) Evaluation of transport of radioactive contaminant in fractured rock. Environ Geol 41:440–450. https://doi.org/10.1007/s002540100410
20. Cho Y-H, Jeong C-H, Hahn P-S (1996) Sorption characteristics of137Cs onto clay minerals: effect of mineral structure and ionic strength. J Radioanal Nucl Chem Artic 204:33–43. https://doi.org/10.1007/BF02060865
21. Dugalic G, Krstic D, Jelic M et al (2010) Heavy metals, organics and radioactivity in soil of western Serbia. J Hazard Mater 177:697–702. https://doi.org/10.1016/j.jhazmat.2009.12.087
22. Elejalde C, Herranz M, Romero F, Legarda F (1996) Correlations between soil parameters and radionuclide contents in samples from Biscay (Spain). Water Air Soil Pollut 89:23–31. https://doi.org/10.1007/BF00300419
23. Hameed PS, Raja P, Satheeshkumar G (2010) Radioactivity study in Nagapattinam Coastal Area (Nagapattinam, Velankanni and Karaikal) in bay of Bengal. Radiat Prot Environ 33:150–154
24. He Q, Walling DE (1996) Interpreting particle size effects in the adsorption of 137Cs and unsupported 210Pb by mineral soils and sediments. J Environ Radioact 30:117–137. https://doi.org/10.1016/0265-931X(96)89275-7
25. Holaday DA (1976) Natural background radiation in the United States. Environ Res 12:376. https://doi.org/10.1016/0013-9351(76)90050-5
26. IAEA (1989) Measurement of radionuclides in food and the environment. International Atomic Energy Agency, Vienna
27. Inigo Valan I, Vijayalakshmi I, Mathiyarasu R et al (2018) Investigation of natural background radiation of sediments in Rameswaram Island, Tamil Nadu, India. Arab J Geosci 11:762. https://doi.org/10.1007/s12517-018-4125-y
28. Iyengar MAR, Kannan V (1994) Natural radiation aspects in the high background areas at Kalpakkam. In: Proceedings 3rd National symposium on environment, Thiruvananthapuram; March, pp 48–55
29. Jackson JE (1991) A use's guide to principal components. Wiley, Hoboken
30. Kannan V, Rajan MP, Iyengar MAR, Ramesh R (2002) Distribution of natural and anthropogenic radionuclides in soil and beach sand samples of Kalpakkam (India) using hyper pure

germanium (HPGe) gamma ray spectrometry. Appl Radiat Isot 57:109–119. https://doi.org/10.1016/S0969-8043(01)00262-7
31. Kanthasamy E, Raj AG (2013) Assessment of radioactivity and estimation of Effective Radiation Dose received by villagers residing at Natural HIgh Background Radiation Areas of Tamilnadu. Int J Innov Res Sci Eng Technol 2:2243–2247
32. Kohn HI (1989) Sources, effects and risks of ionizing radiation. Radiat Res 120:187. https://doi.org/10.2307/3577647
33. Kolb CR (1984) Deltaic plains, engineering geology BT—Applied geology. In: Finkl CW (ed) Springer US, Boston, pp 123–139
34. Krieger R (1981) Radioactivity of construction materials. Betonwork Fertigteil-Techn 47:468–473
35. Li J, Heap AD (2014) Spatial interpolation methods applied in the environmental sciences: a review. Environ Model Softw 53:173–189. https://doi.org/10.1016/j.envsoft.2013.12.008
36. Ligero R, Ramos-Lerate I, Barrera M, Casas-Ruiz M (2001) Relationships between sea-bed radionuclide activities and some sedimentological variables. J Environ Radioact 57:7–19. https://doi.org/10.1016/S0265-931X(00)00213-7
37. Mohapatra S, Sahoo SK, Vinod Kumar A et al (2013) Distribution of norm and 137 cs in soils of the Visakhapatnam region, Eastern India, and associated radiation dose. Radiat Prot Dosimetry 157:95–104. https://doi.org/10.1093/rpd/nct108
38. Murphy HM, Jenkins GP (2010) Observational methods used in marine spatial monitoring of fishes and associated habitats: a review. Mar Freshw Res 61:236. https://doi.org/10.1071/MF09068
39. Panda UC, Rath P, Bramha S, Sahu KC (2010) Application of factor analysis in geochemical speciation of heavy metals in the sediments of a Lake system—Chilika (India): a case study. J Coast Res 265:860–868. https://doi.org/10.2112/08-1077.1
40. Paramasivam K, Ramasamy V, Suresh G (2015) Impact of sediment characteristics on the heavy metal concentration and their ecological risk level of surface sediments of Vaigai river, Tamilnadu, India. Spectrochim Acta Part A Mol Biomol Spectrosc 137:397–407. https://doi.org/10.1016/j.saa.2014.08.056
41. Punniyakotti J, Ponnusamy V (2017) Radionuclides of $^{238}$U, $^{232}$Th and $^{40}$K in beach sand of southern regions in Tamilnadu State, India (Post-Tsunami). Indian J Pure Appl Phys 55:218–230
42. Qureshi AA, Ali M, Waheed A et al (2013) Assessment of radiological hazards of lawrencepur sand, Pakistan using gamma spectrometry. Radiat Prot Dosimetry 157:73–84. https://doi.org/10.1093/rpd/nct105
43. Raja P (2004) Studies on the distribution and bioaccumulation of natural radionuclides in the ecosystem of Pitvhavaram Mangroves, South East Coast, India. Ph.D. Thesis, Bharathidasan University, Tiruchirappalli
44. Ramasamy V, Paramasivam K, Suresh G, Jose MT (2014) Role of sediment characteristics on natural radiation level of the Vaigai river sediment, Tamilnadu, India. J Environ Radioact 127:64–74. https://doi.org/10.1016/j.jenvrad.2013.09.010
45. Ramasamy V, Ponnusamy V, Sabari S et al (2009) Effect of grinding on the crystal structure of recently excavated dolomite. Indian J Pure Appl Phys 47:586–591
46. Ramasamy V, Rajkumar P, Suresh G et al (2011) Determination of level of radioactivity and evaluation of radiation hazardous nature of the recently excavated river sediments. Carpathian J Earth Environ Sci 6:141–146
47. Ramasamy V, Senthil S, Meenakshisundaram V, Gajendran V (2009) Measurement of natural radioactivity in beach sediments from North East coast of Tamilnadu, India. Res J Appl Sci Eng Technol 1(2):54–58
48. Ravisankar R, Chandramohan J, Chandrasekaran A et al (2015) Assessments of radioactivity concentration of natural radionuclides and radiological hazard indices in sediment samples from the East coast of Tamilnadu, India with statistical approach. Mar Pollut Bull 97:419–430. https://doi.org/10.1016/j.marpolbul.2015.05.058
49. Sahoo SK, Kierepko R, Sorimachi A et al (2016) Natural radioactivity level and elemental composition of soil samples from a high background radiation area on eastern coast of India (Odisha). Radiat Prot Dosimetry 171:172–178. https://doi.org/10.1093/rpd/ncw052
50. Sankaran Pillai G, Chandrasekaran S, Sivasubramanian K et al (2018) A review on variation of natural radioactivity along the southeast coast of Tamil Nadu for the past 4 decades (1974–2016). Radiat Prot Dosimetry 179:125–135. https://doi.org/10.1093/rpd/ncx233
51. Satheeshkumar G, Anbusaravanan N, Ps Hameed, Gs Pillai (2012) Environmental radioactivity evaluation in the coastal stretch of Bay of Bengal from Pondycherry to Velanganni (South East coast of India). Radiat Prot Environ 35:90. https://doi.org/10.4103/0972-0464.112351
52. Schuiling RD, de Meijer RJ, Riezebos HJ, Scholten MJ (1986) Grain size distribution of different minerals in a sediment as a function of their specific density: Schuiling, R.D., R.J. de Meijer, H.J. Riezebos and M.J. Scholten, 1985. Geologie Mijnb., 64(2):199–203. Inst Earth Sci Dept Geochem State Univ Deep Sea Res Part B Oceanogr Lit Rev 33:226. https://doi.org/10.1016/0198-0254(86)91111-8
53. Sivakumar S, Chandrasekaran A, Ravisankar R et al (2014) Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of east coast of Tamilnadu using statistical approach. J Taibah Univ Sci 8:375–384. https://doi.org/10.1016/j.jtusci.2014.03.004
54. Sivakumar S, Chandrasekaran A, Ravisankar R et al (2014) Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of east coast of Tamilnadu using statistical approach. J Taibah Univ Sci. https://doi.org/10.1016/j.jtusci.2014.03.004
55. Sivakumar S, Chandrasekaran A, Senthilkumar G et al (2018) Determination of radioactivity levels and associated hazards of coastal sediment from south east coast of Tamil Nadu with statistical approach. Iran J Sci Technol Trans A Sci. https://doi.org/10.1007/s40995-017-0184-2
56. Somasundaram SSN (1998) Studies on the distribution and bioaccumulation of natural radionuclides in the ecosystem of gulf of Mannar, India. Ph.D. thesis, Bharathidasan University, Tiruchirappalli
57. Sowmya M, Senthilkumar B, Seshan BRR et al (2010) Natural radioactivity and associated dose rates in soil samples from Kalpakkam, South India. Radiat Prot Dosimetry 141:239–247. https://doi.org/10.1093/rpd/ncq169
58. Stockburger D (2007) Introductory statistics: concepts, models and apllications. Cengage Learning, Boston
59. SureshGandhi M, Ravisankar R, Rajalakshmi A et al (2014) Measurements of natural gamma radiation in beach sediments of north east coast of Tamilnadu, India by gamma ray spectrometry with multivariate statistical approach. J Radiat Res Appl Sci 7:7–17. https://doi.org/10.1016/j.jrras.2013.11.001
60. Thomas GA, Symonds P (2016) Radiation exposure and health effects—is it time to reassess the real consequences? Clin Oncol 28:231–236. https://doi.org/10.1016/j.clon.2016.01.007
61. Uddin S, Behbehani M (2018) Concentrations of selected radionuclides and their spatial distribution in marine sediments from the northwestern Gulf, Kuwait. Mar Pollut Bull 127:73–81. https://doi.org/10.1016/j.marpolbul.2017.11.052
62. UNSCEAR (2000) The United Nations Scientific Committee on the Effects of Atomic Radiation: Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly. UNSCEAR Rep

63. UNSCEAR (1993) ANNEX A Exposures from natural sources of radiation, UNSCEAR 1993 Report to the general assembly, with scientific annexes
64. UNSCEAR (2008) United Nations Scientific Committee on the Effects of Atomic Radiation, Effects of Ionizing Radiation, Annex E, Exposures From Natural Radiation Sources. UNSCEAR 2008 REPORT, New York. https://doi.org/10.1097/00004032-199907000-00007
65. Vega M, Pardo R, Barrado E, Debán L (1998) Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Water Res 32:3581–3592. https://doi.org/10.1016/S0043-1354(98)00138-9
66. Veiga R, Sanches N, Anjos RM et al (2006) Measurement of natural radioactivity in Brazilian beach sands. Radiat Meas 41:189–196. https://doi.org/10.1016/j.radmeas.2005.05.001
67. Venema L, de Meijer R (2001) Natural radionuclides as tracers of the dispersal of dredge spoil dumped at sea. J Environ Radioact 55:221–239. https://doi.org/10.1016/S0265-931X(00)00198-3
68. Yang Y, Wu X, Jiang Z et al (2005) Radioactivity concentrations in soils of the Xiazhuang granite area, China. Appl Radiat Isot 63:255–259. https://doi.org/10.1016/j.apradiso.2005.02.011