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Research Article

Keywords: Natural radionuclides, Monazite, Geographical processes, Coastal Kerala

Posted Date: March 16th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8970084/v1>

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Additional Declarations: No competing interests reported.

GEOMORPHOLOGICAL CONTROLS ON MONAZITE PLACER FORMATION ALONG THE KOLLAM COAST, SOUTHWEST INDIA

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Abstract

In the present study the investigation on the geographical processes responsible for the formation of monazite placer deposits in the southern coastal region of Kerala were carried out. The sand samples were collected from the southern coastal environment of Kerala. The activity concentration of natural radionuclides viz. ^{40}K , ^{226}Ra and ^{232}Th in the collected sand samples were measured using high efficiency 3"×3" NaI (TI) detector. The radiological parameters were measured and compared with the Indian and World average values. The results show that the activity concentration of natural radionuclides in the collected sand samples was much higher than the values reported in other regions in the World. The enhanced level of natural radioactivity is due to the monazite bearing black sand present in the study area. The geographical processes are the key deciding factor in the distribution of monazite rich black sand in the southern coastal regions of Kerala. The results of the present investigation are discussed detail in the manuscript.

Key words: Natural radionuclides, Monazite, Geographical processes, Coastal Kerala

Introduction

Ionizing radiation, which originates from natural sources, permeates our environment continuously, and this radiation exposure is an inherent aspect of life on Earth that stems from both cosmic and terrestrial origins. One significant source of natural ionizing radiation comes from the Earth itself. Different environmental matrices, including, water bodies, soil, sediments, rocks, plants etc. contain various amounts of radioactive elements including, ^{40}K , ^{232}Th , ^{238}U , and their progenies. For instance, ^{40}K is a naturally occurring isotope of potassium,

constituting a small fraction of the potassium present in soil and rocks. Uranium and thorium and their decay products can leach into groundwater, contributing to background radiation levels. Vegetation absorbs minerals and nutrients from the soil, thereby incorporating trace amounts of radioactive isotopes into their tissues. While the concentrations of these isotopes in plants are typically low, they still contribute to the overall background radiation exposure. Even the materials used in construction may contain traces of radioactive elements. Overall, the presence of primordial radionuclides, such as ^{40}K , ^{238}U , and ^{232}Th , ensures that background radiation is a constant presence in our environment. Understanding and monitoring these radioactive sources are crucial for assessing potential health risks and ensuring radiation safety standards.

In recent decades, there has been a growing focus on epidemiological studies examining the potential health impacts of chronic radiation exposure from natural background radiation. Researchers worldwide have conducted numerous investigations to measure and analyse natural radioactivity levels in various environmental matrices. This ongoing monitoring provides valuable insights into radiation distribution in the environment and helps assess its potential impact on human health. The natural radioactivity levels in environment can vary significantly depending on the geological structure and geographical processes which in turn can influence the occurrence and distribution of natural radionuclides. Some regions of the world, where the radioactivity levels are significantly high, are termed as High Background Radiation Areas (HBRAs). The regions such as Brazil, China, Iran, Australia, France, Japan and India, have garnered attention due to the enhanced background radiation level [1]. In India, locations such as Kalpakkam, Ullal, Chhatrapur, and the southern coastal Kerala have been identified as having elevated background radiation levels [2-4]. The primary sources contributing to this enhanced radiation exposure are the primordial radionuclides present throughout the lithosphere of Earth. These radionuclides are often associated with the minerals such as monazites and zircons, which are abundant in certain geological formations.

Extensive studies conducted by the researchers viz., Vineethkumar et al., (2024), Sajeev et al., (2023), Vinay et al., (2023), Vineethkumar et al., (2021), Vineethkumar et al., (2020), Mahamood et al., (2020), Divya et al., (2019), Ramsiya et al., (2019), Divya et al., (2018), Sreerag et al., (2018), Venunathan et al., (2016), Ramaswami et al., (2013), Shetty et al., (2011), Shetty et al., (2006), Sunta et al., (1993) etc. have confirmed that coastal environment of Kerala is enriched with monazite-bearing black sands. These investigations shown that the coastline environs of Kerala, especially the coastal belt Kollam (coastal regions

of Chavara, Neendakara, and Karunagappalli), is characterized by high levels of natural radioactivity, and classified as HBRA. These studies concluded that the significant natural radioactivity levels in these regions are due to the monazite-bearing black sands [5-19].

Monazite, a rare-earth mineral containing thorium and other radioactive elements, contributes to the elevated radiation levels observed along the coast. The findings of these investigations highlight how crucial it is to comprehend and monitor naturally occurring radioactivity levels, particularly in areas with elevated background radiation. While natural background radiation is generally considered safe at typical levels, prolonged exposure to elevated levels may pose potential health risks to people who reside near these regions. Continuous research in this field is essential for monitoring and mitigating adverse effects on human health and the environment. Monazite is a Cerium containing light-rare-earth element (LREE) phosphate and an accessory mineral found in various rock types. It is one of the important radioactive minerals associated with placer mineral deposits in India.

Monazite is typically found in granitoids with a meta-luminous to pera-luminous composition and is known to contain the radioactive element thorium, along with a rich deposit of rare earth elements, especially Ce, La, and Nd. Monazite occurs within beach placer deposits alongside minerals like ilmenite, leucoxene, zircon, sillimanite, garnet, etc. leading to radionuclide enrichment along the coast. Its significance lies in its potential use in the nuclear industry and the environmental concerns arising from natural radiation [20-22]. Monazite stands as the sole commercial source of rare earth elements, comprising yttrium and the 15 lanthanide elements, including lanthanum, cerium, praseodymium and neodymium [21-22]. Schomberg, a German chemist, discovered the occurrence of monazite-bearing black sands along the southern and southwestern coast of India in 1909 [23-24]. Many other researchers, like Mallik et al., (1987), Raju et al., (1986), Bhattacharya et al., (2005), Anitha et al., (2020), and Veerasamy et al., (2021), have conducted studies that reveal the occurrence of monazite-rich black sand in the coastal belt of Kerala [20-21, 25-27].

The southern coastal region of Kerala, India, is known for its rich mineral deposits, including monazite placer deposits. Monazite mineral contains valuable rare earth elements (REEs) such as cerium, lanthanum, and neodymium. These REEs have significant economic importance due to their diverse applications in various industries, such as electronics, renewable energy technologies, and defence systems. Monazite placers are the accumulations of heavy minerals found within sedimentary environments along coastlines. The deposition is

solemnly the contribution of geomorphological processes that regulate the balance between the upliftment and peneplanation.

The present study, primarily focuses to investigate the geographical and geomorphological processes responsible for the monazite placer depositions in the southern coastal environs of Kerala. The study identifies the source rocks containing monazite-bearing minerals within the proximal region. The study also analyses variations in mineral composition among different placer samples collected from various locations along the southern coastlines of Kerala. The study examines how weathering process contribute to erosion and subsequent transportation of heavy minerals downstream towards coastal areas and analyses how the geographic factors including geology, geomorphology, hydrology, coastal actions, etc. influencing the sedimentation of monazite placers in the shoreline areas of southern Kerala. The understanding of these factors which are responsible for the formation of monazite deposits helps to confirm the source region of parent material. The findings will affect resource exploration, environmental management practices, and further advancements in rare earth element studies. The results of the present investigation are described in detail in this manuscript.

Materials and methods

The Geology of Kerala

Considering the Geology, the rocks of the Western Ghats in the Kerala state are mainly dominated by Charnockite, Coastal sand and alluvium, Laterite, Hornblende gneiss, Biotite-hornblende gneiss, Garnetiferous biotite, Garnet-biotite gneiss with migmatite, and Pink granite gneiss. The Charnockite and Hornblende gneiss forms 56% of the total lithology of the state. The Charnockite is formed from the combination of igneous and metamorphic rocks in a geosynclinal environment [28]. The Hornblende gneiss is mostly formed from the retrogression of Charnockite rock. When relating the evolution of Western Ghats with the metamorphic transition of Charnockite rock to Hornblende gneiss, it can be stated that the Charnockite rocks are formed due to the solidification of magma at the initial stage [29]. Later, the rock underwent regional metamorphism; it has been transferred to high-grade granulite. Due to the thermal collapse stage, the retrogression effect transferred the Charnockite rock to Hornblende gneiss. Biotite-hornblende gneiss, Garnetiferous biotite, Garnet-biotite gneiss with Migmatite and Pink granite gneiss form the majority of the metamorphic rocks other than the Hornblende

gneiss. The Laterite, covering an area of 1932 sq.km (4.97%), is the major sedimentary rock of the region. Coastal sand and alluvium soil, as deposition features, covers 10.31% of the net geographical area of Kerala.

The geographical analysis of a sediment deposit starts with the identification of the parent material [30]. As stated, the endogenetic force which sculptured the southern plateau region of India has created the Western Ghats. This has given the answer for how the Western Ghats formed. However, what the Western Ghats is made of can only lead to the understanding of parent material which is behind the major depositional features of Kerala. From the Highlands to Lowland including Midland the depositional material is very much influenced by the characteristics of the source material which has created the Western Ghats. The Geology and the Lithology of the Ghats region contribute to the major depositional material of Western Coastal Plains of India [31-32].

While considering the geology of Kerala, more than half of the Western Ghats region is dominated by Charnockite and associated rocks. Hence, understanding its mineralogy is very much required to establish the presence of monazite placers in the coastal sands of Kerala. Charnockite is considered as a lower crustal felsic rock. The name 'Charnockite' was given by Sir Thomas Holland for the rock received from a hill near Chennai called Pallavaram [33]. Charnockite rocks are always confusion for scientists and geologists in their categorization. Charnockite in the south Indian context is considered as an igneous rock (magmatic in origin) as well as a metamorphic rock (dehydrated granite) [34]. The southern granulite terrain and Eastern Ghats belt of the great peninsular region of India is dominated by Charnockite massifs [35]. The mineralogy of the Charnockite rock includes orthopyroxene, clinopyroxene, hornblende, biotite, garnet, plagioclase and potassium feldspar. The rock also contains minor minerals like monazite, magnetite, ilmenite, pyrite, pyrrhotite, apatite, zircon, spinel, and sapphirine [33, 36-37]. Different studies have identified the presence of monazite in the Charnockite rocks of south India and the Western Ghats region [8, 21, 38].

Study area

Kollam district is situated within the geographical coordinates of 8°45' N to 9°10' N latitude and 76°25' E to 77°15' E longitude. It has a coastal plain of length 37 km and is a well-reported HBRA of Kerala, especially Chavara beach, which is heavily enriched with minerals such as monazite, ilmenite, zircon, rutile, etc. The two rivers, Kallada and Ithikkara, flow through this district. The confluence of the Kulathupuzha, the Chendurmi and the Kalthuruthy

forms the Kallada River. It has a catchment area of 1699 sq. kilometres. The Ithikkara River is a small river originating from the Madathuri kunnu, which is about 800 feet in size and has a catchment area of 642 sq. kilometres [39]. The location map of sampling stations of Kollam district is given in Fig. 2.

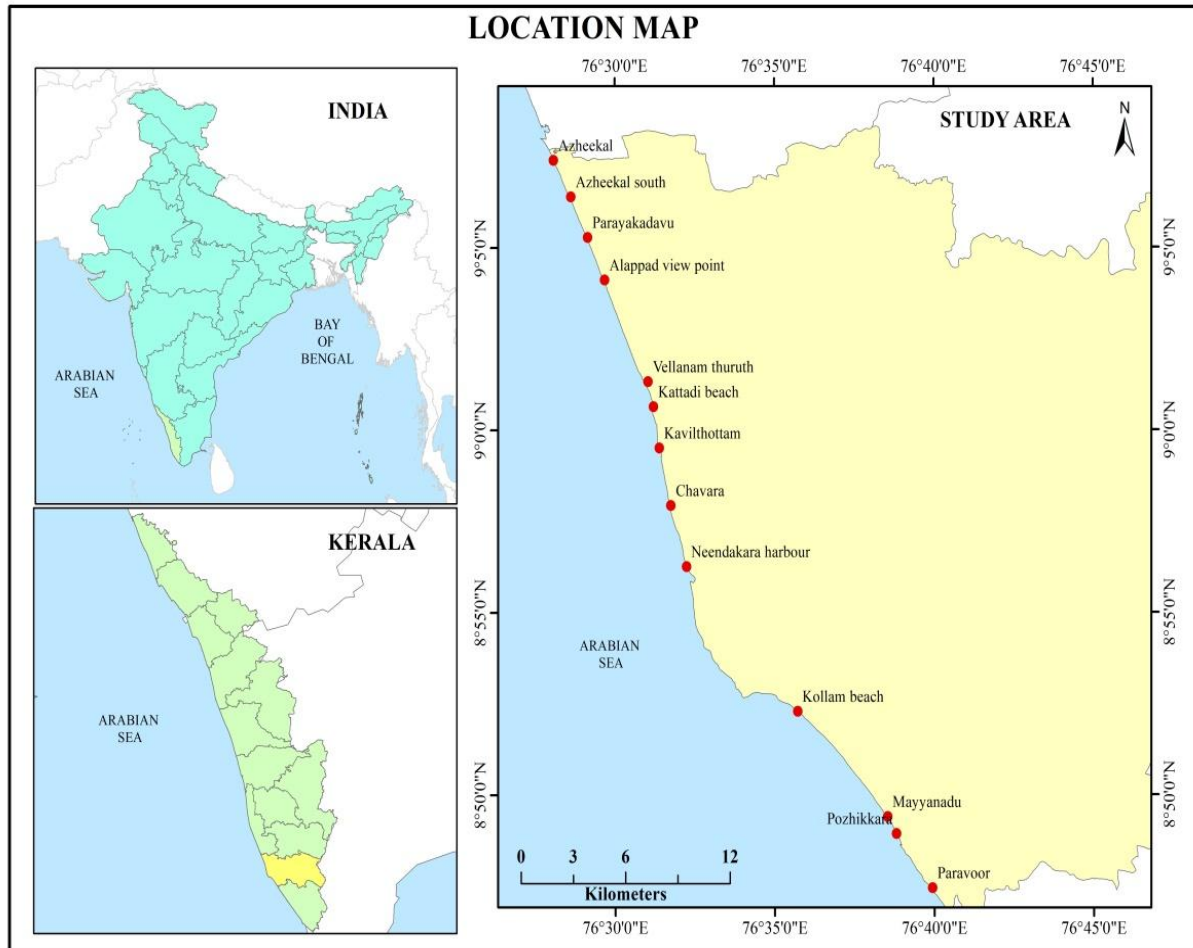


Fig. 1 Location map of the study area

Measurement of activity concentration of radionuclides

Nuclear instrumentation

For the present investigation, a portable scintillation-based gamma radiation survey meter (UR-705) with sensitivity of $1 \mu\text{Rh}^{-1}$ capable of measuring dose rates ranging from 0 to 10,000 μRh^{-1} with a calibration accuracy better than $\pm 15\%$ (specified with Cs-137 standard source) from 100 $\mu\text{R/h}$ onwards was used to measure ambient gamma radiation levels in the study area. A GR611M model gamma-ray spectrometer, made by Nucleonix Systems in India, is used to quantify the activity concentration of natural radionuclides. It has a $3'' \times 3''$ flat type NaI(Tl) scintillation detector with a detection resolution that ranges from 8.0 to 9.5% for gamma-ray

energy at 662 keV of ^{137}Cs . An X-ray diffractometer (Model: Rigaku, Smartlab, Japan) was utilized to identify the heavy minerals in the collected samples.

Sample collection

Thirteen sampling stations such Paravoor, Pozhikkara, Mayyanad, Kollam, Neendakara harbour, Chavara, Kavilthottam, Kattil, Vellanamthuruth, Alappad viewpoint, Parayakadavu, Azheekal south, and Azheekal in the Kollam district was selected for the present investigation. A total of 106 sand samples were collected from various locations along the coastal belt of Kollam which are identified using a gamma radiation survey meter.

The samples were collected by following a standard procedure served by the Environmental Measurements Laboratory (EML) procedures manual, 1983 [40]. The sample collection was carried out in April 2021. The smooth surface areas were selected for the sample collection. About 1 m² surface area was marked, and the stones, grasses, and root mats from the area were removed, and mixed thoroughly for homogeneity of the samples. Samples weighing approximately 2.5 kg were collected from a depth of 10-25 cm, packaged in polythene bags, and then taken to the Payyanur College laboratory for preparation and further analytical procedures. The latitude and longitudes of the sampling points are given in Table 1.

Table 1. Latitude and Longitude of sampling locations of Kollam district

Sampling locations	Latitude	Longitude
Paravoor	8.790807	76.665668
Pozhikkara	8.815531	76.6469
Mayyanad	8.823251	76.642262
Kollam Beach	8.871504	76.595331
Neendakara harbor	8.937619	76.537332
Chavara	8.965489	76.529225
Kavilthottam	8.991817	76.523147
Kattil Beach	9.010712	76.520123
Vellanamthuruth	9.022108	76.517271
Alappad viewpoint	9.068542	76.494667
Parayakadavu	9.088022	76.485819
Azheekal South	9.106545	76.477058

Azheekal	9.132447	76.463858
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Sample processing

The collected samples were initially crushed and homogenized using a 1000 μm mesh to allow only the sand, silt and clay portion of the sediment and to eliminate the plant debris, corals, shells and small pebbles. After cleaning, the samples underwent oven drying at 110°C for 24 hours to eliminate moisture. The oven dried samples were then sieved through a $250\mu\text{m}$ mesh and sealed in 250ml capacity air-tight plastic containers designed to match the standard geometry of IAEA reference standards (RG-K, RG-U, and RG-Th), with an approximate dry weight of 400g per sample. These standards are used for the efficiency of the spectrometer for required energies. The prepared samples were stored for 30 days to attain secular equilibrium. Then the gamma-ray spectrometric analysis was used to quantify the activity concentrations of natural radionuclides such as ^{40}K , ^{226}Ra , and ^{232}Th in the collected samples [40-42, 2, 18].

Activity concentration of ^{40}K , ^{226}Ra , ^{232}Th

The primary source of ambient radioactivity in the earth's crust is primordial radionuclides like potassium-40 (^{40}K), radium-226 (^{226}Ra), and thorium-232 (^{232}Th), as well as their daughter products. They constantly undergo nuclear disintegration and release gamma (γ) radiations, which comprise the terrestrial background radiation in a particular environment. Based on the energy peaks of the radionuclides and their progenies, the measurement of gamma active radionuclides in the sand samples was conducted using the gamma-ray spectrometry technique.

According to IAEA, 1989 data, the natural radioisotope ^{40}K produces gamma radiation with energy of 1460 keV, or 10.67%. Gamma spectrometry is commonly employed to measure ^{226}Ra activity, but its detection is complicated by interference from other radionuclides and low emission probabilities. However, the gamma emissions from the decay products of ^{226}Ra , ^{214}Pb and ^{214}Bi , are abundant, interference-free, and easily measurable. By establishing equilibrium between ^{226}Ra and its daughter nuclides, the activity of ^{226}Ra can be accurately measured using its daughter ^{214}Bi , which emits gamma rays at 609 keV and 1764 keV, via gamma spectrometry using HPGe or NaI(Tl) detectors. Thus, the activity of ^{226}Ra can be easily measured using its daughter ^{214}Bi with an abundance of 15.65% employing gamma spectrometry by NaI (Tl) detector. Gamma spectrometry offers a simple and non-destructive method for determining the

activity content of ^{232}Th in environmental samples. The activity concentration of ^{232}Th can be measured by analyzing the gamma energy peaks associated with the decays of its progeny, including ^{212}Bi , ^{228}Ac , ^{208}Tl , and ^{212}Pb . However, the most common approach is to measure the 2614 keV gamma line of ^{208}Tl , which has a percentage abundance of 36%, after achieving secular equilibrium.

A gamma spectrometer with a 3"×3" flat-type NaI(Tl) detector was used to determine the activity concentrations (in Bqkg^{-1}) of ^{40}K , ^{226}Ra , and ^{232}Th in the collected sand samples. The device was first calibrated using a few standard sources, and the efficiencies for the radionuclides ^{40}K , ^{226}Ra , and ^{232}Th were determined using the corresponding standard RG-K, RG-U, and RG-Th. Subsequently, gamma-ray spectral analysis was performed to determine the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th for each processed sample. To ensure accuracy, the spectrometer is regularly calibrated using standard sources provided by the International Atomic Energy Agency (IAEA) in Vienna. The calibration process was carried out by using the standard sources of ^{22}Na , ^{133}Ba , ^{60}Co , and ^{137}Cs .

The efficiency of the spectrometer was determined using standardized reference materials from the IAEA in Vienna, specifically RG-K, RG-U, and RG-Th, which represent standards for ^{40}K , ^{226}Ra , and ^{232}Th , respectively. The ^{226}Ra activity was estimated from the 1765 keV photo peak of its daughter product ^{214}Bi . The ^{40}K activity was calculated using the 1461 keV gamma line, while the ^{232}Th activity was determined using the 2614 keV gamma line of its daughter product, ^{208}Tl .

To determine the detector's efficiency (E), apply the formula below [41];

$$E (\%) = N \times \frac{100}{C} \times \frac{100}{a}$$

C represents the activity of the standard source (Bq), N is the background-subtracted count under the photopeak, and a is the percentage abundance of the gamma-ray. The resulting efficiencies for the RG-K, RG-U, and RG-Th standards were 1.33, 1.17, and 0.87, respectively

To determine the Minimum Detectable Activity (MDA) of a radionuclide, the following formula is applied [41];

$$\text{MDA (Bqkg}^{-1}\text{)} = \text{CL} \times \frac{B}{T} \times \frac{100}{E} \times \frac{100}{a} \times \frac{1000}{W}$$

CL is the confidence level, T is the counting time (seconds), B is the background counts in the peak region, E is the efficiency of the detector for that particular energy, a is the percentage

abundance of the gamma-ray, W is the weight of the sample (grams). The resulting MDAs for gamma spectrometry were found to be 1.2 Bqkg⁻¹ for ⁴⁰K, 0.7 Bqkg⁻¹ for ²²⁶Ra, and 0.1 Bqkg⁻¹ for ²³²Th. Each sample was counted for 30,000 seconds to ensure that the counting error was minimized.

The ⁴⁰K activity was calculated using the 1461 keV gamma line (10.67% of abundance). To determine the activities of ²²⁶Ra and ²³²Th, the gamma emissions from their respective daughter products were analyzed. Specifically, the 1764 keV photopeak of ²¹⁴Pb (15.65% abundance) was used to estimate ²²⁶Ra activity, while the 2614 keV gamma line of ²⁰⁸Tl (36% abundance) was employed to determine ²³²Th activity [5, 9, 43].

The activity (A) was estimated using the equation:

$$A \text{ (Bqkg}^{-1}\text{)} = (C \pm SD) \times \frac{100}{E} \times \frac{100}{a} \times \frac{1000}{W}$$

Where, C is the net counts per second, SD is the standard deviation, E is the photo peak efficiency (%) of the detector, 'a' is the abundance of the characteristic gamma ray and W is the weight of the sample (grams).

Radiological parameters

Despite calculating the activity concentrations of radionuclides, these values alone may not accurately indicate of the comprehensive radiological hazards present in the study area. As a result, to assess radiological threats to the people who residing near the study area, it is required to compute several radiological parameters, including Radium equivalent activity, absorbed dose rate in air and annual effective dose (indoor and outdoor).

Radium equivalent activity (Ra_{eq})

The distribution of ⁴⁰K, ²²⁶Ra, and ²³²Th in environmental matrices is often heterogeneous, which means that activity concentrations can vary substantially depending on the type of sample being analyzed [44]. To provide a unified measure of radiation hazard, the radium equivalent activity (Ra_{eq}) parameter is widely used. This single index allows for a direct comparison of the specific activities of samples containing varying amounts of ⁴⁰K, ²²⁶Ra, and ²³²Th, thereby assessing the uniformity of radiation exposure [44-45]. It is defined as the weighted sum of the activity concentrations of three radionuclides [46].

The Ra_{eq} is calculated using the equation [47];

$$R_{\text{eq}} (\text{Bqkg}^{-1}) = 0.077 C_K + C_{\text{Ra}} + 1.43 C_{\text{Th}}$$

Where, C_K , C_{Ra} , and C_{Th} are the activities (Bqkg^{-1}) of ^{40}K , ^{226}Ra , and ^{232}Th , respectively. The relationship assumes that the radiation doses generated by 13 Bqkg^{-1} of ^{40}K , 1 Bqkg^{-1} of ^{226}Ra , and 0.7 Bqkg^{-1} of ^{232}Th are identical, thereby providing a basis for comparison [48-49].

Absorbed dose rate (D) in air

To estimate the absorbed dose rates in air 1 meter above the ground due to terrestrial gamma radiation, the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th were measured and converted using appropriate factors. Since the contributions from other radionuclides are considered insignificant, the absorbed dose rate can be calculated as follows [50];

$$D (\text{nGyh}^{-1}) = 0.0417 C_K + 0.462 C_{\text{Ra}} + 0.621 C_{\text{Th}}$$

C_K , C_{Ra} , and C_{Th} are the activities (Bqkg^{-1}) of ^{40}K , ^{226}Ra , and ^{232}Th , respectively. The conversion factors of 0.0417, 0.462, and 0.621 (nGyh^{-1} per Bqkg^{-1}) were employed to calculate the absorbed dose rate in air from the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th , respectively, in soil. [15,45, 50].

Annual effective dose (AED)

The following equation is used to calculate the annual effective dose rates for both indoor and outdoor exposures;

$$\text{AED} (\text{mSvy}^{-1}) = D \times 8760 \times 0.8 \times 0.7 \times 10^{-6} (\text{Indoor})$$

$$\text{AED} (\text{mSvy}^{-1}) = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} (\text{Outdoor})$$

D represents the absorbed dose rate in air (nGyh^{-1}), while 8760 is the number of hours per annum. The conversion factor of 0.7 is used to convert the absorbed dose rate in air to the equivalent dose in human tissue (SvGy^{-1}) [50]. The factors 0.8 and 0.2 are the occupancy factors for indoor and outdoor gamma radiations, respectively [9].

X-Ray diffractometer (XRD) analysis

The exact composition of the numerous minerals found in the samples collected for this study, as well as information regarding their origin, is revealed through this analysis. The present study employs X-ray diffractometer analysis to find out the correlation between the activity concentrations of primordial radionuclides and the mineral presence in the sand samples collected from Kerala's southern coastal areas. Prior to XRD analysis, the samples were dried

and sieved to a size of less than 125 microns. The resulting XRD spectra were used to identify the minerals present in the sand samples, with mineral identification confirmed using JCPDS data.

Geographical analysis

The study aims to determine how geographical processes have influenced the occurrence of monazite placer deposits in the southern coastal regions of Kerala. To identify the factors influencing the deposition of monazite bearing black sands in the coastal region, the lithology map and drainage pattern of the study area were overlaid and possible conclusions were drawn. These maps revealed areas with monazite-bearing rocks and river sources, allowing for the identification of potential monazite sources and deposit locations. The results were then interpreted in the context of natural radionuclide activity and coastal dynamics.

Statistical analysis

Statistical analysis was performed using ‘Statistical Package for the Social Science’, SPSS 20.0, with calculations of statistical parameters such as arithmetic mean, median, standard deviation, skewness, and kurtosis. Additionally, frequency distribution histograms were generated to illustrate the data analysis.

Results and discussion

The activity concentration of natural radionuclides such as ^{40}K , ^{226}Ra , ^{232}Th in the collected sand samples were measured and the radiological parameters associated with the activity concentration is calculated and compared with the values reported in the other regions of the World. The influence of geographical factors for the monazite deposition also identified and the results are discussed in detail below. The activity concentration of radionuclides in the sand samples collected from the coastal regions of Kollam were given in Table 2 to Table 14 and the associated radiological parameters were given in Table 15 to Table 28.

Table 2. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the coastal regions of Paravoor

Sampling locations	Activity concentrations (Bqkg^{-1})		
	^{40}K	^{226}Ra	^{232}Th
PR1	338±8	868±31	4275±130
PR2	334±10	861±30	4270±132
PR3	335±12	864±32	4272±135
PR4	335±12	865±25	4273±130
PR5	336±10	875±28	4280±135

PR6	330±15	860±26	4266±130
PR7	328±15	855±38	4257±136
PR8	332±12	857±35	4260±135
Mean	333.50	863.12	4269.12

Table 3. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the coastal regions of Pozhikkara

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
PP1	169±15	486±20	1846±140
PP2	168±18	470±18	1830±135
PP3	143±12	458±25	1674±135
PP4	156±15	465±18	1710±142
PP5	174±15	478±15	1762±138
PP6	154±10	432±18	1418±135
PP7	158±12	448±15	1365±135
PP8	160±18	440±15	1388±140
Mean	160.25	459.62	1624.12

Table 4. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Mayyanad

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
MY1	340±20	860±18	2274±150
MY2	325±18	846±22	2016±145
MY3	314±20	848±25	1898±148
MY4	308±20	846±20	1848±150
MY5	286±15	828±18	1694±150
MY6	265±20	786±18	1610±152
MY7	262±18	779±20	1590±145
Mean	300	827.571	1847.142

Table 5. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Kollam

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
KL1	178±8	574±28	2070±80
KL2	182±10	577±30	2074±80
KL3	180±12	568±31	2065±82
KL4	185±10	562±30	2060±75
KL5	173±10	558±30	2466±80
KL6	164±8	560±28	2418±78
KL7	156±15	558±35	2389±80

KL8	158±12	546±32	2316±75
Mean	172	562.87	2232.25

Table 6. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Neendakara harbor

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
NK1	154±10	548±35	1026±45
NK2	164±10	550±32	1031±48
NK3	168±8	546±30	1014±42
NK4	174±10	538±34	995±45
NK5	168±12	524±35	989±40
NK6	171±10	542±30	986±42
NK7	169±8	534±28	965±45
NK8	145±10	538±32	948±45
Mean	164.125	540.00	994.25

Table 7. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Azheekal

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
AK1	135±8	590±38	1649±105
AK2	128±10	418±35	1418±108
AK3	168±12	661±35	1896±105
AK4	149±12	646±36	1815±110
AK5	220±10	729±38	2935±108
AK6	184±8	718±36	1948±108
AK7	216±10	732±32	2940±110
AK8	221±10	735±35	2946±105
Mean	177.625	653.625	2193.375

Table 8. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Azheekal South

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
AKS1	194±8	738±40	1254±80
AKS2	208±12	740±42	1296±88
AKS3	228±10	735±38	1315±86
AKS4	238±12	742±40	1360±80
AKS5	194±8	738±42	2509±78
AKS6	259±12	712±42	2482±85

AKS7	246±10	756±40	2618±82
AKS8	288±12	756±38	2128±80
Mean	231.875	739.625	1870.250

Table 9. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the coastal regions of Parayakadavu

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
PKD1	590±10	848±30	3165±125
PKD2	586±15	839±25	2886±120
PKD3	578±12	826±28	2418±120
PKD4	575±12	785±25	1989±115
PKD5	571±8	798±22	2110±118
PKD6	584±15	812±35	2156±118
PKD7	580±12	818±35	2308±115
PKD8	588±15	805±30	2351±120
Mean	581.50	816.37	2422.87

Table 10. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Alappad viewpoint

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
AV1	158±5	560±25	1932±60
AV2	160±8	590±30	1915±55
AV3	164±10	588±28	1946±65
AV4	158±5	544±23	1914±52
AV5	139±5	536±20	1908±50
AV6	126±2	498±28	1898±45
AV7	118±2	464±25	1875±48
AV8	118±2	460±25	1868±48
Mean	142.625	530.0	1907.0

Table 11. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples Vellanamthuruth

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
VT1	138±8	248±20	865±50
VT2	130±8	364±28	898±55
VT3	146±10	258±25	884±55
VT4	148±10	255±25	878±52
VT5	159±15	264±25	896±55

VT6	142±10	274±28	911±58
VT7	154±12	268±28	908±58
VT8	136±8	244±20	854±52
Mean	144.125	271.875	886.750

Table 12. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Kattil

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
KB1	798±10	1115±40	7846±125
KB2	784±15	1098±38	7825±120
KB3	678±10	986±35	7218±125
KB4	546±15	936±35	6818±120
KB5	526±10	868±28	6136±118
KB6	824±15	1248±40	7996±125
KB7	838±18	1276±40	8116±125
KB8	489±8	812±28	5526±115
KB9	468±8	806±28	4186±115
Mean	661.22	1016.11	6851.88

Table 13. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Chavara

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
CH1	998±18	2215±125	15263±510
CH2	848±18	2968±120	22148±510
CH3	789±15	2646±120	20874±508
CH4	768±15	2621±118	25548±548
CH5	746±15	2608±120	23356±510
CH6	716±10	2428±118	19786±510
CH7	658±10	2318±118	18416±508
CH8	546±10	2096±115	18628±508
CH9	396±8	1985±115	18158±505
CH10	328±8	1618±112	19281±505
Mean	679.30	2350.30	20145.8

Table 14. Activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of Kavilthottam

Sampling locations	Activity concentrations (Bqkg ⁻¹)		
	^{40}K	^{226}Ra	^{232}Th
KT1	86±10	468±25	1218±45
KT2	79±8	452±22	968±38
KT3	75±8	438±20	939±35
KT4	78±10	428±20	948±35
KT5	74±8	409±25	896±32

KT6	75±10	415±25	878±35
KT7	69±6	406±23	845±35
KT8	72±8	395±20	789±30
Mean	76	426.37	938.12

Eight sampling points were identified at Paravoor Beach, and sand samples were collected from each point. The average gamma radiation exposure rate is $461.625 \mu\text{Rh}^{-1}$ and the related average absorbed dose rate in the air is $4016.138 \text{ nGyh}^{-1}$, is substantially higher than the global average of 57 nGyh^{-1} [50]. Table 2 gives the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th measured in sand samples from the coastal areas of Paravoor Beach. The activity of ^{40}K is found to vary in between 328 ± 15 and $338\pm8 \text{ Bqkg}^{-1}$ with a mean value, 333.50 Bqkg^{-1} . The activity of ^{226}Ra is ranges from 855 ± 38 to $875\pm28 \text{ Bqkg}^{-1}$ with an average, 863.12 Bqkg^{-1} . The activity of ^{232}Th is found to vary from $4257\pm136 \text{ Bqkg}^{-1}$ to $4280\pm135 \text{ Bqkg}^{-1}$ with the mean value of $4269.12 \text{ Bqkg}^{-1}$. The findings indicate elevated mean activity concentrations of ^{226}Ra and ^{232}Th in Paravoor Beach sand samples, exceeding the world averages of 33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively. In contrast, the mean activity concentration of ^{40}K is lower than the world average value of 420 Bqkg^{-1} [50].

A total of eight sand samples were collected from Pozhikkara Beach, representing different sampling points. The average gamma radiation exposure rate and the absorbed dose rate are $144.625 \mu\text{Rh}^{-1}$ and $1258.225 \text{ nGyh}^{-1}$, respectively. The average absorbed dose rate in air is greater than the world average value of 57 nGyh^{-1} [50]. The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples from Pozhikkara coastal area are summarized in Table 3. The activity of ^{40}K varies in a rage, 143 ± 12 – $174\pm15 \text{ Bqkg}^{-1}$ with a mean value of 160.25 Bqkg^{-1} . The activity of ^{226}Ra is found to range from 432 ± 18 to $486\pm20 \text{ Bqkg}^{-1}$ with an average of 459.62 Bqkg^{-1} . Similarly, the ^{232}Th activity concentration is found to vary from $1365\pm135 \text{ Bqkg}^{-1}$ to $1846\pm140 \text{ Bqkg}^{-1}$ with mean value of $1624.12 \text{ Bqkg}^{-1}$. The results indicate that the average activity concentrations of ^{226}Ra and ^{232}Th in the sand samples of Pozhikkara Beach are elevated, surpassing the world average values of 33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively. However, the mean activity concentration of ^{40}K is below the world average of 420 Bqkg^{-1} [50].

The sand samples were collected from seven different sampling points at Mayyanad Beach. The average gamma radiation exposure rate and the corresponding absorbed dose rates are $189.285 \mu\text{Rh}^{-1}$ and 1646.7 nGyh^{-1} . The average absorbed dose rate in air is observed to exceed the global average value of 57 nGyh^{-1} [50]. Table 4 provides an overview of the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples collected from the coastal regions

of Mayyanad. The activity of ^{40}K ranges from 262 ± 18 to 340 ± 20 Bqkg^{-1} with an average of 300 Bqkg^{-1} . The activity of ^{226}Ra varies from 779 ± 20 to 860 ± 18 Bqkg^{-1} with an average of 827.571 Bqkg^{-1} . Finally, the activity of ^{232}Th is found to vary from 1590 ± 145 Bqkg^{-1} to 2274 ± 150 Bqkg^{-1} with a mean value of 1847.142 Bqkg^{-1} . Compared to the world average values, the mean activity concentrations of ^{226}Ra and ^{232}Th in the sand samples of Mayyanad Beach are higher (33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively), whereas the mean activity of ^{40}K is lower (420 Bqkg^{-1}) [50].

The average gamma radiation exposure rate in the coastal areas of Kollam Beach is 227.75 μRh^{-1} . The related average absorbed dose rate in air is 1981.288 nGyh^{-1} , which is found to be larger than the world average value of 57 nGyh^{-1} [50]. The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in sand samples from the coastal areas of Kollam Beach are given in Table 5. The activity of ^{40}K is found to vary from 156 ± 15 to 185 ± 10 Bqkg^{-1} with an average of 172.00 Bqkg^{-1} . The activity of ^{226}Ra is found to be ranged from 546 ± 32 to 577 ± 30 Bqkg^{-1} with a mean value of 562.87 Bqkg^{-1} . Finally, the ^{232}Th activity concentration ranges from 2060 ± 75 Bqkg^{-1} to 2466 ± 80 Bqkg^{-1} with a mean value of 2232 Bqkg^{-1} . The mean activity concentrations of ^{226}Ra and ^{232}Th in Kollam Beach sand samples exceed the global averages, with values of 33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively. In contrast, the mean activity of ^{40}K is below the global average of 420 Bqkg^{-1} [50].

Sand samples from eight sampling points at Neendakara were assessed for gamma-ray exposure rates. The average gamma radiation exposure rate in the coastal areas of Neendakara is 106.125 μRh^{-1} . The related average absorbed dose rate in air is 916.762 nGyh^{-1} , larger than the world average value of 57 nGyh^{-1} . Table 6 provides an overview of the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples collected from the coastal regions of Neendakara. The activity of ^{40}K is found to vary from 145 ± 10 to 174 ± 10 Bqkg^{-1} with a mean value of 164.125 Bqkg^{-1} . The activity of ^{226}Ra ranges between 524 ± 35 and 550 ± 32 Bqkg^{-1} with a mean value of 540.00 Bqkg^{-1} . Similarly, the ^{232}Th activity concentration is found to vary from 948 ± 45 Bqkg^{-1} to 1031 ± 48 Bqkg^{-1} with a mean value of 994.25 Bqkg^{-1} . A comparison with global averages reveals that the sand samples from Neendakara harbor have higher mean activity concentrations of ^{226}Ra and ^{232}Th (33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively) and a lower mean activity of ^{40}K (420 Bqkg^{-1}) [50].

The average gamma radiation exposure rates and the corresponding absorbed dose rates are 222.625 μRh^{-1} and 1936.825 nGyh^{-1} , respectively. Table 7 provides the activity

concentrations of radionuclides present in sand samples of Azheekal Beach. ^{40}K activity is found to vary in a range of 128 ± 10 – 221 ± 10 Bqkg^{-1} with an average of 177.625 Bqkg^{-1} . The activity of ^{226}Ra is in between 418 ± 35 and 735 ± 35 Bqkg^{-1} with an average of 653.625 Bqkg^{-1} . Finally, the activity of ^{232}Th is found to vary from 1418 ± 108 Bqkg^{-1} to 2946 ± 105 Bqkg^{-1} with an average of 2193.375 Bqkg^{-1} . Compared to global averages, the sand samples from Azheekal Beach have higher mean activity concentrations of ^{226}Ra and ^{232}Th (33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively) and a lower mean activity of ^{40}K (420 Bqkg^{-1}) [50].

The coastal areas of Azheekal South have an average gamma radiation exposure rate of 223 μRh^{-1} and an average absorbed dose rate in air of 1940.1 nGyh^{-1} . This absorbed dose rate exceeds the world average value of 57 nGyh^{-1} , highlighting elevated levels of gamma radiation in this region. The activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the collected sand samples of coastal areas of Azheekal South are summarized in Table 8. The measured activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples from Azheekal South range from 194 ± 8 to 288 ± 12 Bqkg^{-1} , 712 ± 42 to 756 ± 40 Bqkg^{-1} , and 1254 ± 80 Bqkg^{-1} to 2618 ± 82 Bqkg^{-1} with corresponding mean values of 231.87 Bqkg^{-1} , 739.62 Bqkg^{-1} , and 1870.25 Bqkg^{-1} . A comparison with global averages reveals that the mean activity concentrations of ^{226}Ra and ^{232}Th are higher, while the mean activity of ^{40}K is lower than the global average [50].

The average gamma radiation exposure rate is 234.625 μRh^{-1} , and the average absorbed dose rate in air is 2041.237 nGyh^{-1} . This average absorbed dose rate is substantially higher than the global average value of 57 nGyh^{-1} . The activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples of the coastal areas of Parayakadavu are summarized in Table 9. The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples from Parayakadavu Beach were determined to be in the ranges of 571 ± 8 – 590 ± 10 Bqkg^{-1} (mean: 581.50 Bqkg^{-1}), 785 ± 25 – 848 ± 30 Bqkg^{-1} (mean: 816.375 Bqkg^{-1}), and 1989 ± 115 – 3165 ± 125 Bqkg^{-1} (mean: 2422.87 Bqkg^{-1}), respectively. Notably, the mean activity concentrations of these radionuclides exceed the corresponding world average values of 420 Bqkg^{-1} , 33 Bqkg^{-1} , and 45 Bqkg^{-1} [50].

The average gamma radiation exposure rate in the coastal areas of Alappad viewpoint is 205.375 μRh^{-1} , with a corresponding average absorbed dose rate in air of 1786.737 nGyh^{-1} . Notably, this average absorbed dose rate exceeds the world average value of 57 nGyh^{-1} . The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples from the Alappad viewpoint are summarized in Table 10. The results show that the mean activity concentrations of ^{226}Ra and ^{232}Th are higher than the world average values of 33 Bqkg^{-1} and 45 Bqkg^{-1} , respectively,

while the mean activity of ^{40}K is lower than the world average value of 420 Bqkg^{-1} , indicating variations in the levels of these radionuclides in the study area. [50].

The coastal areas of Vellanamthuruth have average gamma-ray exposure rates and absorbed dose rates in air of $91.62 \mu\text{Rh}^{-1}$ and 797.13 nGyh^{-1} , respectively. The corresponding activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples are summarized in Table 11. The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples from Vellanamthuruth are summarized as follows: ^{40}K ranges from $130\text{-}159 \text{ Bqkg}^{-1}$ with a mean of $144.125 \text{ Bqkg}^{-1}$, ^{226}Ra ranges from $244\text{-}364 \text{ Bqkg}^{-1}$ with a mean of $271.875 \text{ Bqkg}^{-1}$, and ^{232}Th ranges from $854\text{-}911 \text{ Bqkg}^{-1}$ with a mean of $886.750 \text{ Bqkg}^{-1}$. These results indicate that the mean activity concentrations of ^{226}Ra and ^{232}Th exceed the world average values, while the mean activity of ^{40}K is lower [50].

The coastal areas have an average gamma radiation exposure rate of $612.77 \mu\text{Rh}^{-1}$ and an average absorbed dose rate in air of $5331.16 \text{ nGyh}^{-1}$, which is elevated compared to the world average value. A summary of the activity concentrations of radionuclides from the coastal areas of Kattil Beach is provided in Table 12. The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th are found to range from 468 ± 8 to $838\pm 18 \text{ Bqkg}^{-1}$, 806 ± 28 to $1276\pm 40 \text{ Bqkg}^{-1}$, and $4186\pm 115 \text{ Bqkg}^{-1}$ to $8116\pm 125 \text{ Bqkg}^{-1}$, with mean values of 661.22 Bqkg^{-1} , $1016.11 \text{ Bqkg}^{-1}$, and $6851.88 \text{ Bqkg}^{-1}$, respectively. Notably, these mean values exceed the world average values of 420 Bqkg^{-1} , 33 Bqkg^{-1} , and 45 Bqkg^{-1} for ^{40}K , ^{226}Ra , and ^{232}Th , respectively [50].

The coastal environs of Chavara Beach, a prominent HBRA on India's southwest coast, were investigated in this study. The beach sand, enriched with monazite minerals from the Kallada River, was sampled at 10 locations. The gamma radiation exposure rates and absorbed dose rates in air, revealing average values of $1639.5 \mu\text{Rh}^{-1}$ and $14263.65 \text{ nGyh}^{-1}$, respectively. These values are substantially higher than the world average value of 57 nGyh^{-1} . The activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples from Chavara Beach are presented in Table 13. The results show that the activity concentrations of these radionuclides vary widely, with mean values significantly higher than the world average values. Specifically, the mean activity concentrations are 679.30 Bqkg^{-1} for ^{40}K , 2350.3 Bqkg^{-1} for ^{226}Ra , and $20145.8 \text{ Bqkg}^{-1}$ for ^{232}Th [50].

The average gamma radiation exposure rate and absorbed dose rate in air for the coastal environs of Kavilthottam are $100.875 \mu\text{Rh}^{-1}$ and $877.612 \text{ nGyh}^{-1}$, respectively, which are higher than the world average values. Table 14 gives the activity concentrations of ^{40}K , ^{226}Ra , and

^{232}Th in the sand samples from Kavilthottam. The results show that the activity concentrations of ^{40}K , ^{226}Ra , and ^{232}Th in the sand samples of Kavilthottam range from 69-86 Bqkg⁻¹, 395-468 Bqkg⁻¹, and 789-1218 Bqkg⁻¹, respectively, with corresponding mean values of 76 Bqkg⁻¹, 426.37 Bqkg⁻¹, and 935.12 Bqkg⁻¹. A comparison with world average values reveals that the mean activity concentrations of ^{226}Ra and ^{232}Th are elevated, while the mean activity of ^{40}K is relatively low [50].

Table 15 Radiological parameters of the radionuclides in the sand samples of Paravoor

Sample ID	Radium equivalent activity, (R_{eq}) (Bqkg ⁻¹)	Absorbed dose (D) (nGyh ⁻¹)	Annual Effective Dose (mSvy ⁻¹)	
			Indoor	Outdoor
PR1	7007.276	3069.885	15.059	3.764
PR2	6992.818	3063.379	15.027	3.756
PR3	6998.755	3066.049	15.040	3.760
PR4	7001.185	3067.132	15.046	3.761
PR5	7021.272	3076.141	15.090	3.772
PR6	6985.79	3060.267	15.012	3.753
PR7	6967.766	3052.284	14.973	3.743
PR8	6974.364	3055.238	14.987	3.746
Mean	6993.653	3063.797	15.029	3.757

Table 16. Radiological parameters of the radionuclides in the sand samples of Pozhikkara

Sample ID	Radium equivalent activity, (R_{eq}) (Bqkg ⁻¹)	Absorbed dose, (D) (nGyh ⁻¹)	Annual Effective Dose (mSvy ⁻¹)	
			Indoor	Outdoor
PP1	3138.793	1377.945	6.759	1.689
PP2	3099.836	1360.575	6.674	1.668
PP3	2862.831	1257.113	6.166	1.541
PP4	2922.312	1283.245	6.295	1.573
PP5	3011.058	1322.293	6.486	1.621
PP6	2471.598	1086.583	5.330	1.332
PP7	2412.116	1061.229	5.205	1.301
PP8	2437.16	1071.9	5.258	1.314
Mean	2794.463	1227.610	6.022	1.505

Table 17. Radiological parameters of the radionuclides in the sand samples of Mayyanad

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
MY1	4138	1823.652	8.946	2.236
MY2	3753.905	1656.340	8.125	2.031
MY3	3586.318	1583.527	7.768	1.942
MY4	3512.356	1551.303	7.610	1.902
MY5	3272.442	1446.436	7.095	1.773
MY6	3108.705	1373.992	6.740	1.685
MY7	3072.874	1358.213	6.662	1.665
Mean	3561.954	1572.542	7.714	1.928

Table 18. Radiological parameters of the radionuclides in the sand samples of Kollam

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose, D ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
KL1	3547.806	1558.080	7.643	1.910
KL2	3556.834	1562.117	7.663	1.915
KL3	3534.81	1552.287	7.614	1.903
KL4	3522.045	1546.618	7.587	1.896
KL5	4097.701	1796.396	8.812	2.203
KL6	4030.368	1767.136	8.668	2.167
KL7	3986.282	1747.870	8.574	2.143
KL8	3870.046	1697.076	8.325	2.081
Mean	3768.236	1653.447	8.111	2.027

Table 19. Radiological parameters of the radionuclides in the sand samples of Neendakara harbor

Sample ID	Radium equivalent activity (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
NK1	2027.038	896.743	4.399	1.099
NK2	2036.958	901.189	4.420	1.105
NK3	2008.956	888.951	4.360	1.090
NK4	1974.248	873.706	4.286	1.071
NK5	1951.206	863.262	4.234	1.058
NK6	1965.147	869.840	4.267	1.066
NK7	1926.963	853.020	4.184	1.046
NK8	1904.805	843.310	4.136	1.034
Mean	1974.415	873.753	4.286	1.071

Table 20. Radiological parameters of the radionuclides in the sand samples of Azheekal

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose, (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
AK1	2958.465	1302.238	6.388	1.597
AK2	2455.596	1079.031	5.293	1.323
AK3	3385.216	1489.803	7.308	1.827
AK4	3252.923	1431.780	7.023	1.755
AK5	4942.99	2168.607	10.638	2.659
AK6	3517.808	1549.096	7.599	1.899
AK7	4952.832	2172.931	10.659	2.664
AK8	4964.797	2178.251	10.685	2.671
Mean	3803.828	1671.467	8.199	2.049

Table 21. Radiological parameters of the radionuclides in the sand samples of Azheekal South

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose, (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
AKS1	2546.158	1127.7798	5.532	1.383
AKS2	2609.296	1155.3696	5.667	1.416
AKS3	2633.006	1165.6926	5.718	1.429
AKS4	2705.126	1197.2886	5.873	1.468
AKS5	4340.808	1907.1348	9.355	2.338
AKS6	4281.203	1881.0663	9.227	2.306
AKS7	4518.682	1985.3082	9.739	2.434
AKS8	3821.216	1682.7696	8.254	2.063
Mean	3431.936	1512.801	7.421	1.855

Table 22. Radiological parameters of the radionuclides in the sand samples of Parayakadavu

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose, (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
PKD1	5419.38	2381.844	11.684	2.921
PKD2	5011.102	2204.260	10.813	2.703
PKD3	4328.246	1907.292	9.356	2.339
PKD4	3673.545	1621.816	7.955	1.988
PKD5	3859.267	1702.796	8.353	2.088
PKD6	3940.048	1738.372	8.527	2.131
PKD7	4163.1	1835.37	9.003	2.250
PKD8	4212.206	1856.400	9.106	2.276
Mean	4325.861	1906.019	9.350	2.337

Table 23. Radiological parameters of the radionuclides in the sand samples of Alappad viewpoint

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
AV1	3334.926	1465.080	7.187	1.796
AV2	3340.77	1468.467	7.203	1.800
AV3	3383.408	1486.960	7.294	1.823
AV4	3293.186	1446.510	7.096	1.774
AV5	3275.143	1438.296	7.055	1.763
AV6	3221.842	1413.988	6.936	1.734
AV7	3154.336	1383.663	6.787	1.696
AV8	3140.326	1377.468	6.757	1.689
Mean	3267.992	1435.054	7.039	1.759

Table 24. Radiological parameters of the radionuclides in the sand samples of Vellanamthuruth

Sample ID	Radium equivalent activity (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
VT1	1495.576	657.495	3.225	0.806
VT2	1658.15	731.247	3.587	0.896
VT3	1533.362	674.248	3.307	0.826
VT4	1521.936	669.219	3.282	0.820
VT5	1557.523	685.014	3.360	0.840
VT6	1587.664	698.240	3.425	0.856
VT7	1578.298	694.105	3.405	0.851
VT8	1475.692	648.733	3.182	0.795
Mean	1551.025	682.288	3.347	0.836

Table 25. Radiological parameters of the radionuclides in the sand samples of Kattil

Sample ID	Radium equivalent activity, (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose, D ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
KB1	12396.226	5420.772	26.592	6.648
KB2	12348.118	5399.293	26.486	6.621
KB3	11359.946	4966.182	24.362	6.090
KB4	10727.782	4689.178	23.003	5.750
KB5	9682.982	4233.406	20.767	5.191
KB6	12745.728	5576.452	27.355	6.838
KB7	12946.406	5664.492	27.787	6.946
KB8	8751.833	3827.181	18.774	4.693
KB9	6828.016	2991.393	14.674	3.668
Mean	10865.226	4752.039	23.311	5.827

Table 26. Radiological parameters of the radionuclides in the sand samples of Chavara

Sample ID	Radium equivalent activity (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
CH1	24117.936	10543.269	51.721	12.930
CH2	34704.936	15160.485	74.371	18.592
CH3	32556.573	14218.107	69.748	17.437
CH4	39213.776	17108.235	83.926	20.981
CH5	36064.522	15740.080	77.214	19.303
CH6	30777.112	13438.699	65.924	16.481
CH7	28703.546	12534.690	61.490	15.372
CH8	28776.082	12559.108	61.609	15.402
CH9	27981.432	12209.701	59.895	14.973
CH10	29215.086	12734.694	62.471	15.617
Mean	31211.100	13624.707	66.837	16.709

Table 27. Radiological parameters of the radionuclides in the sand samples of Kavilthottam

Sample ID	Radium equivalent activity (R_{eq}) ($Bqkg^{-1}$)	Absorbed dose (D) ($nGyh^{-1}$)	Annual Effective Dose ($mSvy^{-1}$)	
			Indoor	Outdoor
KT1	2216.362	976.180	4.788	1.197
KT2	1842.323	813.246	3.989	0.997
KT3	1786.545	788.602	3.868	0.967
KT4	1789.646	789.696	3.873	0.968
KT5	1695.978	748.459	3.671	0.917
KT6	1676.315	740.095	3.630	0.907
KT7	1619.663	715.194	3.508	0.877
KT8	1528.814	675.461	3.313	0.828
Mean	1769.455	780.867	3.830	0.957

The radiological parameters derived from the activity concentrations of radionuclides in the sand samples collected from the Paravoor coastal region are summarized in Table 15. The mean radium equivalent activity is $6993.65 Bqkg^{-1}$. The mean absorbed dose is $3063.79 nGyh^{-1}$. The averages of indoor and outdoor annual effective doses are $15.02 mSvy^{-1}$ and $3.75 mSvy^{-1}$, respectively. A comparison with global averages reveals that all radiation indices in this study are substantially higher. The radiation indices of the sand samples collected from Pozhikkara Beach are summarized in Table 16, which reports the mean values of radium equivalent activity, absorbed dose rate, and indoor and outdoor AED as; $2794.463 Bqkg^{-1}$, $1227.610 nGyh^{-1}$, $6.022 mSvy^{-1}$ and $1.505 mSvy^{-1}$ respectively. The radiological indices far exceed the world average values, which are $370 Bqkg^{-1}$, $57 nGyh^{-1}$, and $0.48 mSvy^{-1}$, respectively, indicating elevated levels of radioactivity. The radiological parameters of the sand samples from Mayyanad Beach are summarized in Table 17, which includes the mean values of radium equivalent activity, absorbed dose rate, and indoor and outdoor AED as; $3561.954 Bqkg^{-1}$, $1572.542 nGyh^{-1}$, $7.714 mSvy^{-1}$, and $1.928 mSvy^{-1}$, respectively. Compared to the global average values, the radiological indices are remarkably higher, with values of $370 Bq kg^{-1}$, $57 nGyh^{-1}$, and $0.48 mSvy^{-1}$, respectively, being significantly exceeded [50].

Table 18 provides an overview of the radiological parameters measured in the sand samples collected from Kollam Beach. The averages of radium equivalent activity, absorbed dose rate, and indoor and outdoor AED are $3768.236 Bqkg^{-1}$, $1653.447 nGyh^{-1}$, $8.111 mSvy^{-1}$

and 2.027 mSvy^{-1} , respectively. All those radiological indices are significantly larger than the world average values (370 Bqkg^{-1} , 57 nGyh^{-1} and 0.48 mSvy^{-1} , respectively). The radiological parameters of the sand samples from Neendakara harbor are summarized in Table 19. The mean radium equivalent activity, absorbed dose rate, and indoor and outdoor annual effective doses are significantly higher than the world average values, with values of $1974.415 \text{ Bqkg}^{-1}$, $873.753 \text{ nGyh}^{-1}$, 4.286 mSvy^{-1} , and 1.071 mSvy^{-1} , respectively. Table 20 provides an overview of the radiological parameters determined for the sand samples of Azheekal Beach. Compared to the world average values, the mean values of radium equivalent activity, absorbed dose rate, and indoor and outdoor AED are substantially higher, with values of $3803.823 \text{ Bqkg}^{-1}$, $1671.467 \text{ nGyh}^{-1}$, 8.199 mSvy^{-1} , and 2.049 mSvy^{-1} , respectively, indicating elevated radiological indices [50].

The radiological parameters for the sand samples from Azheekal South, presented in Table 21, reveal mean values of $3431.936 \text{ Bqkg}^{-1}$ for radium equivalent activity, $1512.801 \text{ nGyh}^{-1}$ for absorbed dose rate, and 7.421 mSvy^{-1} and 1.855 mSvy^{-1} for indoor and outdoor AED, respectively. These values exceed the world average values, indicating elevated radiological indices in the study area. The radiological parameters for the sand samples from Parayakadavu, presented in Table 22, reveal mean values of $4325.8617 \text{ Bqkg}^{-1}$ for radium equivalent activity, $1906.019 \text{ nGyh}^{-1}$ for absorbed dose rate, and 9.350 mSvy^{-1} and 2.337 mSvy^{-1} for indoor and outdoor AED, respectively. These values exceed the world average values, suggesting that the study area has higher radiation levels than the global average. Table 23 provides the radiological parameters for the sand samples collected from the coastal areas of Alappad viewpoint. The mean radium equivalent activity, absorbed dose rate, and indoor and outdoor AED values are $3267.992 \text{ Bqkg}^{-1}$, $1435.054 \text{ nGyh}^{-1}$, 7.039 mSvy^{-1} , and 1.759 mSvy^{-1} , respectively. These radiological indices exceed the world average values, indicating elevated radiation levels in the study area. The radiological parameters presented in Table 24 for the sand samples from Vellanamthuruth show mean values of $1551.025 \text{ Bqkg}^{-1}$, $682.288 \text{ nGyh}^{-1}$, 3.347 mSvy^{-1} , and 0.836 mSvy^{-1} for radium equivalent activity, absorbed dose rate, and indoor and outdoor AED, respectively. These values are elevated compared to the world average values [50].

The data presented in Table 25 demonstrate that the radiation indices for the sand samples from Kattil Beach far exceed the world average values. The mean values for radium equivalent activity, absorbed dose rate, and indoor and outdoor AED are $10865.22 \text{ Bqkg}^{-1}$, $4752.039 \text{ nGyh}^{-1}$, 23.311 mSvy^{-1} , and 5.827 mSvy^{-1} , respectively, indicating a high radiation

threat in the study area. The data presented in Table 26 demonstrate that the radiological parameters for the sand samples from Chavara Beach are significantly elevated compared to the world average values. The mean values for radium equivalent activity, absorbed dose rate, and indoor and outdoor AED are $31211.10 \text{ Bq kg}^{-1}$, $13624.707 \text{ nGy h}^{-1}$, 66.83 mSv y^{-1} , and 16.70 mSv y^{-1} , respectively, indicating a high level of radiation exposure in the area. The data presented in Table 27 demonstrate that the radiological parameters for the sand samples from Kavalthottam, including radium equivalent activity, absorbed dose rate, and indoor and outdoor AED, with mean values of $1769.45 \text{ Bq kg}^{-1}$, $780.86 \text{ nGy h}^{-1}$, 3.83 mSv y^{-1} , and 0.95 mSv y^{-1} , respectively, are substantially higher than the world average values [50].

The statistical parameters calculated from the activity concentrations of radionuclides are given in Table 28. Figures 2, 3 and 4 represent the frequency distribution curves of activity concentration of the radionuclides ^{40}K , ^{226}Ra and ^{232}Th , respectively, and these curves indicate that the radionuclides exhibit normal distribution in the sand samples of Kollam coastal zone. The standard deviation of ^{40}K and ^{226}Ra is lower than mean value, which reveals that a moderately high degree of uniformity occurs in the activity concentrations of those radionuclides. Meanwhile, the standard deviation of ^{232}Th is higher than mean activity, which implies the significant deviations in the spatial distribution of ^{232}Th radionuclide. Table shows that the activities of radionuclides under study show positive skewness. This indicates that there is an asymmetric tail extending towards the values that are more positive with respect to the mean value and exhibit a left leaning distribution curve. In addition, the radionuclides show positive values of kurtosis, which indicates that the distribution of respective radionuclides in the study area is relatively peak distribution in the sand samples of Kollam coastal zone [8, 51].

Table 28. Statistical parameters for the activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th (Bq kg^{-1}) in the sand samples of Kollam coastal zone

Statistical parameters	^{40}K	^{226}Ra	^{232}Th
Minimum	69	244	789
Maximum	998	2968	25548
Mean	304.83	805.17	4063.54
Standard deviation	223.32	554.56	5542.19
Kurtosis	0.521	5.151	5.467
Skewness	1.257	2.322	2.535
Frequency distribution	Positively skewed	Positively skewed	Positively skewed

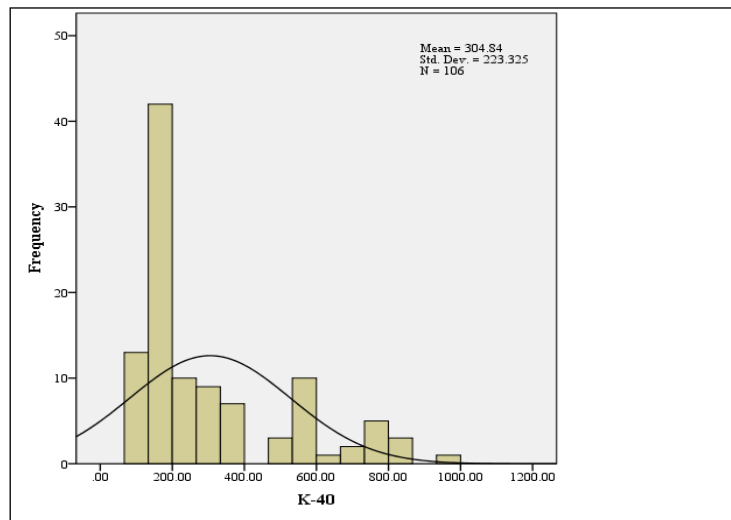


Fig. 2 Frequency distribution of ^{40}K in the sand samples of Kollam coastal regions

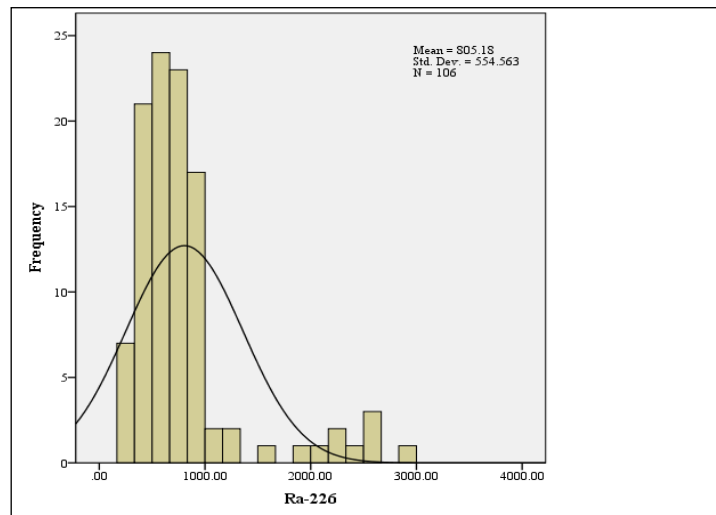


Fig. 3 Frequency distribution of ^{226}Ra in the sand samples of Kollam coastal regions

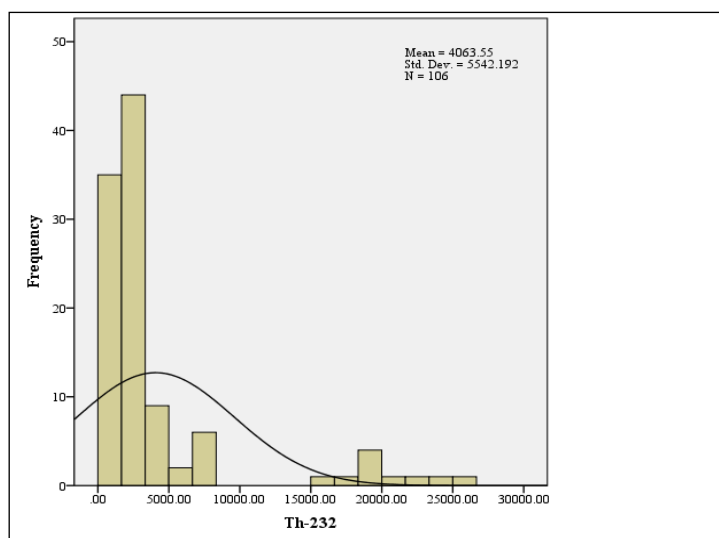


Fig. 4 Frequency distribution of ^{232}Th in the sand samples of Kollam coastal regions

Fig. 5 illustrates the correlation between the absorbed dose rate (nGyh^{-1}) and the activity concentrations of ^{40}K , revealing a poor positive correlation with a coefficient, $R^2 = 0.514$. In contrast, a strong positive correlation is observed between the absorbed dose rate (nGyh^{-1}) and the activity concentrations of ^{226}Ra and ^{232}Th (Bqkg^{-1}), with correlation coefficients of 0.932 and 0.999, respectively (Figures 6 and 7). This correlation is further substantiated by the XRD spectra sand samples collected from each coastal regions of the district (Figures 8-20), which confirm the presence of monazite minerals in the coastal belt of Kollam district.

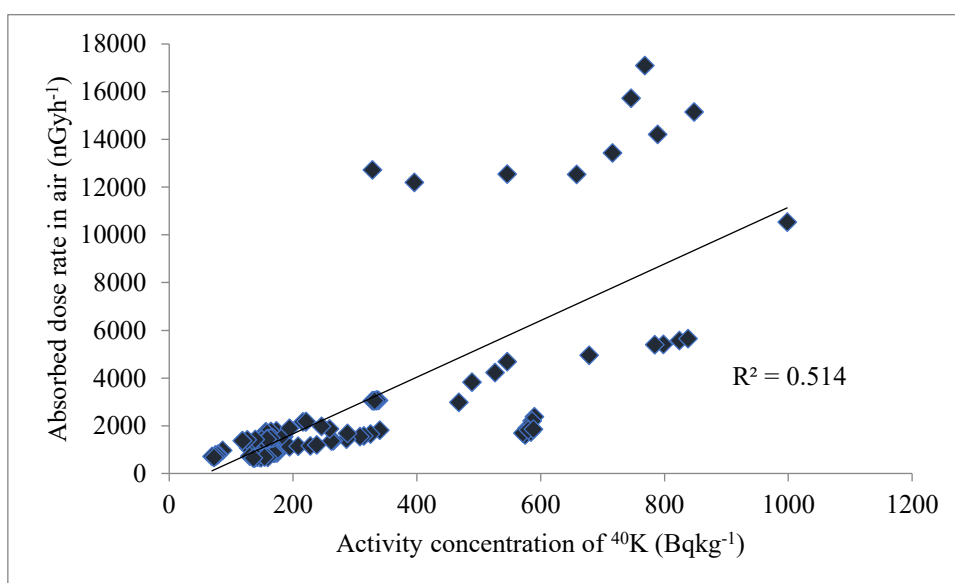


Fig. 5 Correlation between the activity of ^{40}K and the absorbed dose rate in the sand samples of Kollam coastal zone

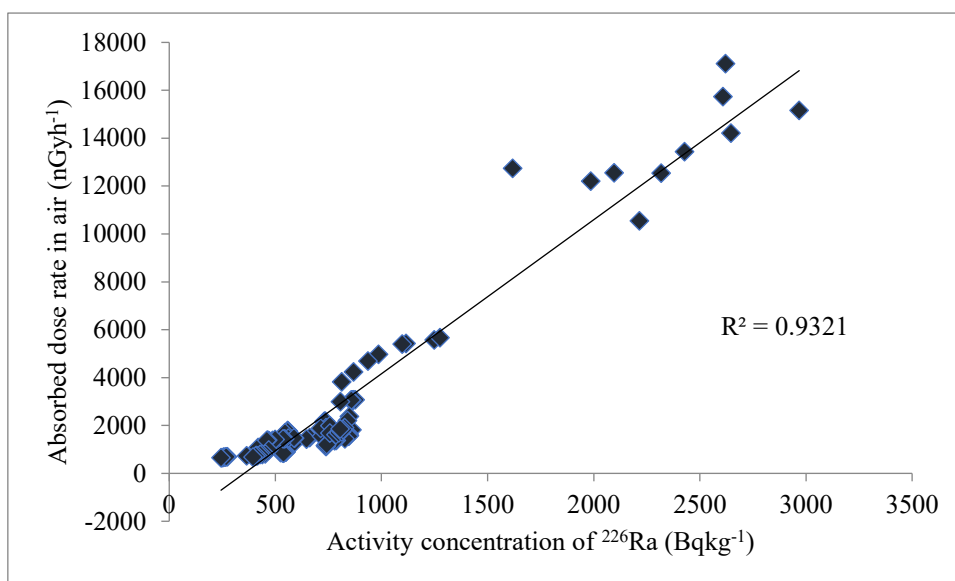


Fig. 6 Correlation between the activity of ^{226}Ra and the absorbed dose rate in the sand samples of Kollam coastal zone

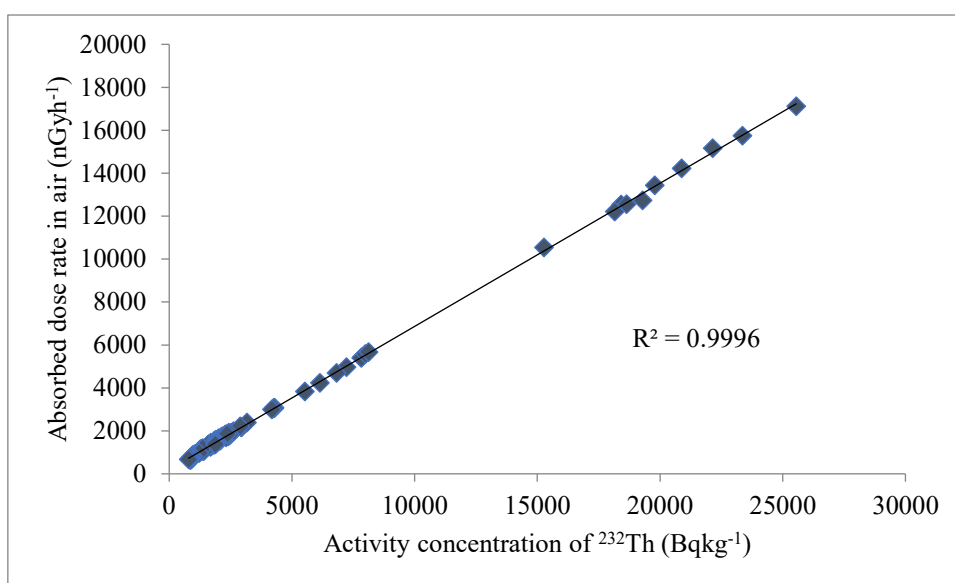


Fig. 7 Correlation between the activity of ^{232}Th and the absorbed dose rate in the sand samples of Kollam coastal zone

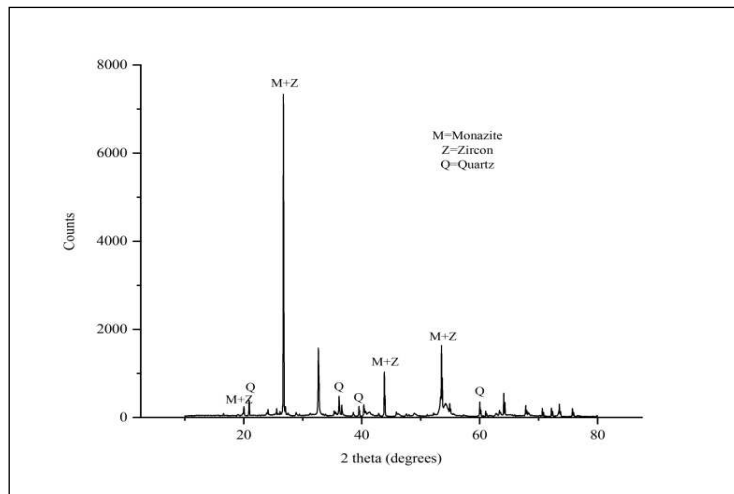


Fig. 8 XRD Spectrum of sand samples from Paravoor Beach

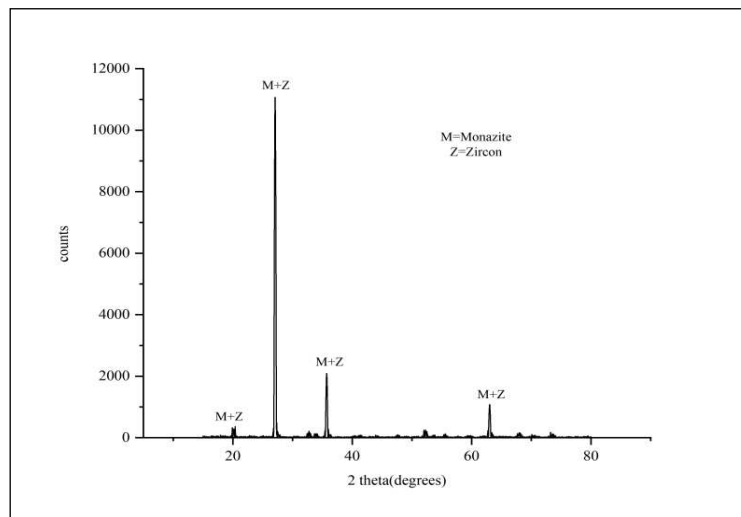


Fig. 9 XRD Spectrum of sand samples from Pozhikkara

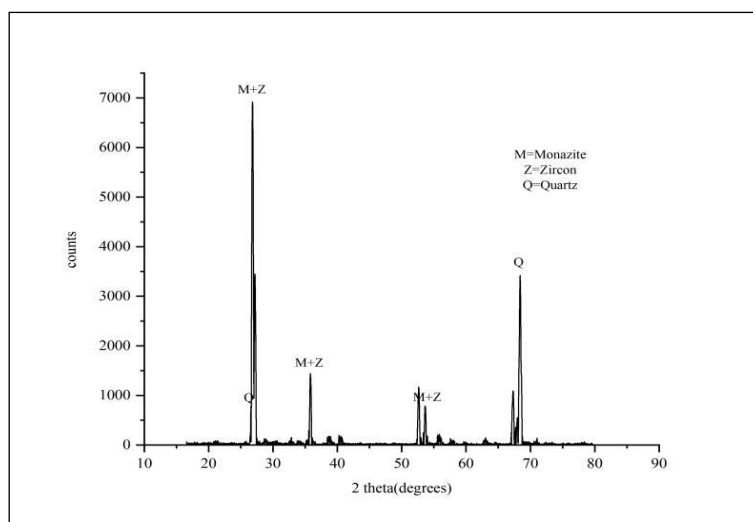


Fig. 10 XRD spectrum of sand samples from Mayyanad Beach

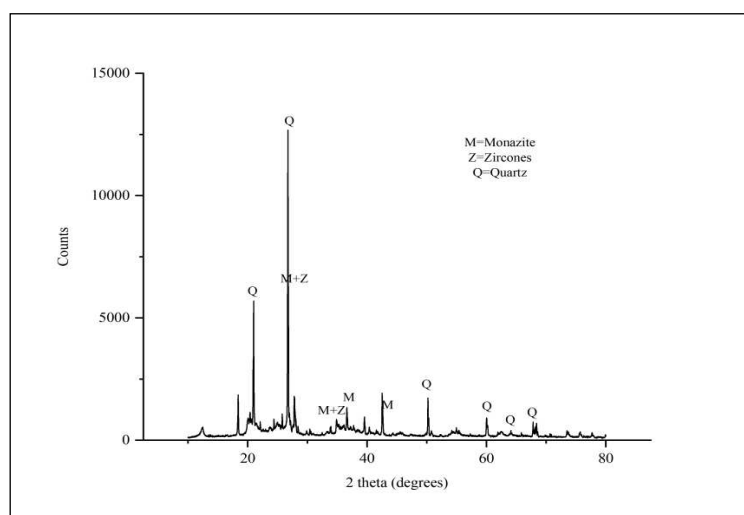


Fig. 11 XRD spectrum of sand samples from Kollam Beach

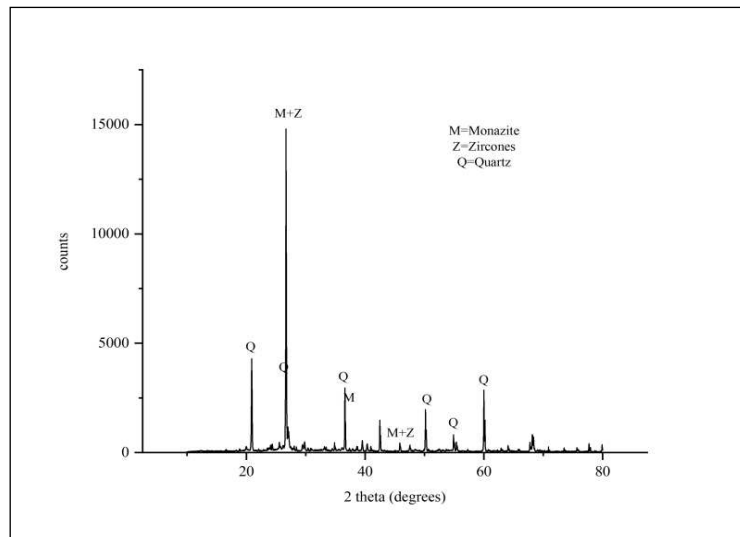


Fig. 12 XRD spectrum of sand samples from Neendakara harbor

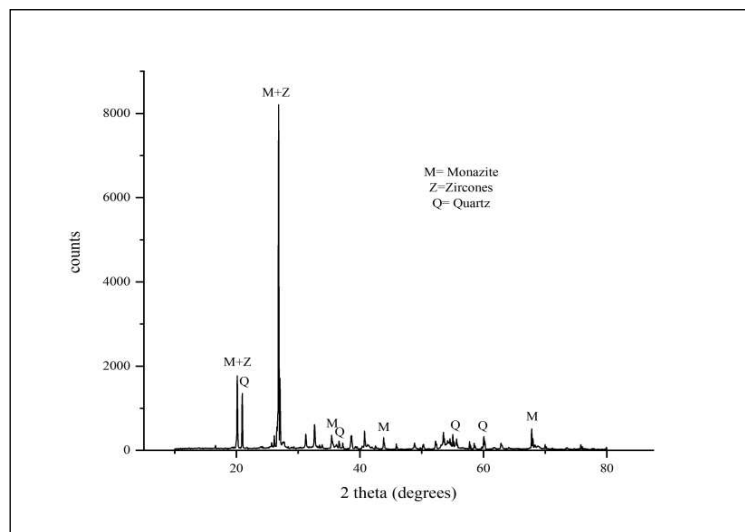


Fig. 13 XRD spectrum of sand samples from Azheekal Beach

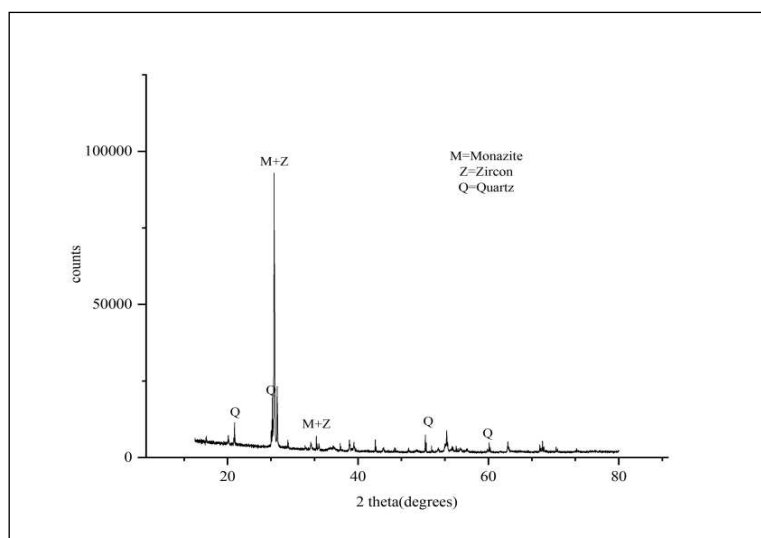


Fig. 14 XRD spectrum of sand samples from coastal areas of Azheekal South

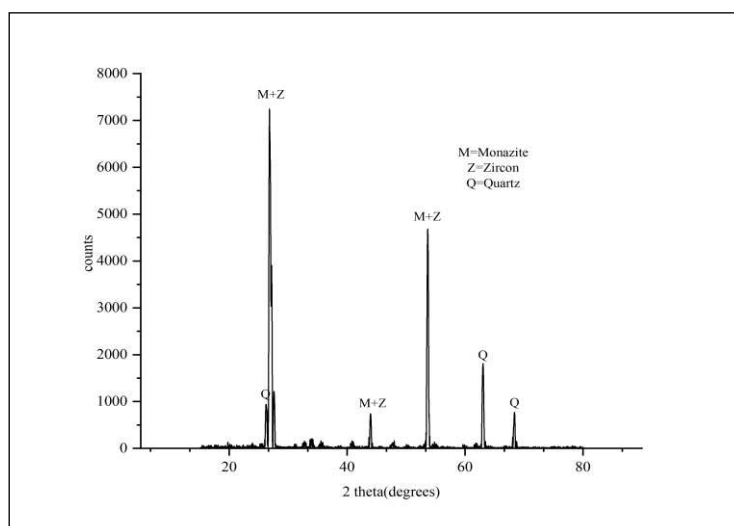


Fig. 15 XRD spectrum of the sand samples from Parayakadavu Beach

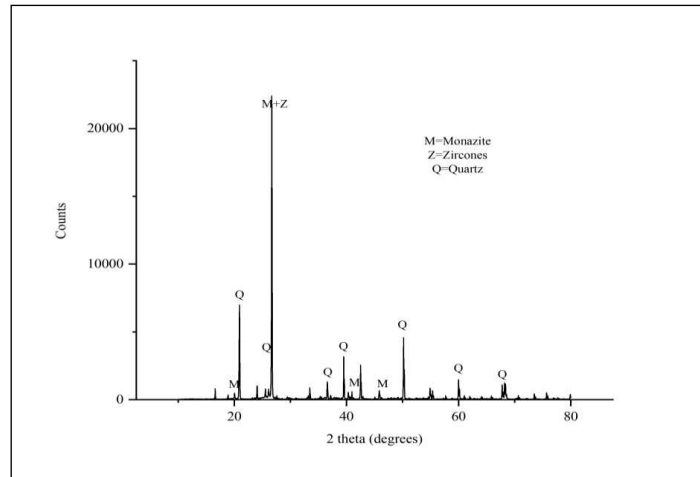


Fig. 16 XRD spectrum of sand samples from Alappad viewpoint

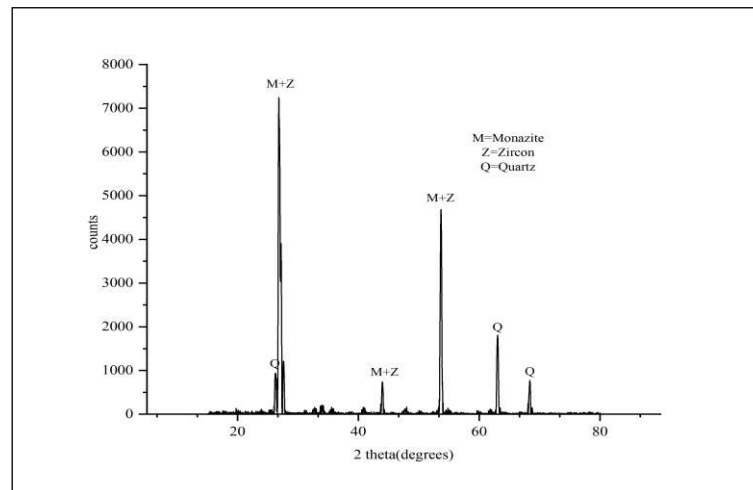


Fig. 17 XRD spectrum of sand samples from Vellanamthuruth

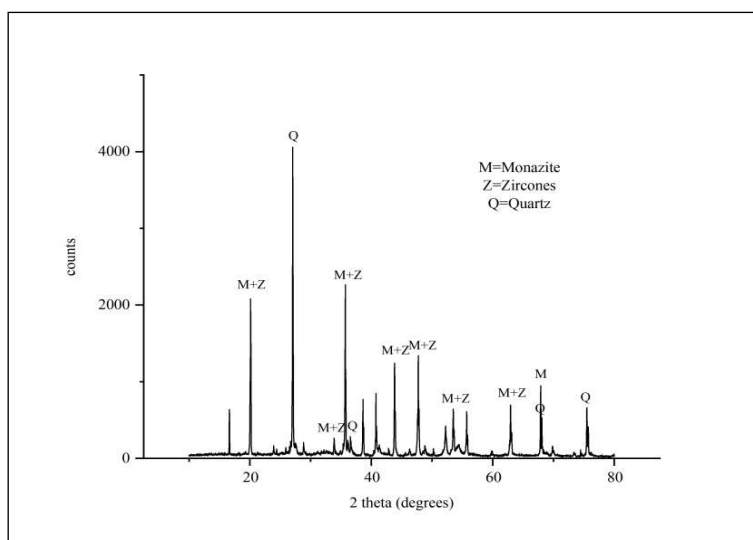


Fig. 18 XRD spectrum of sand samples from Kattil Beach

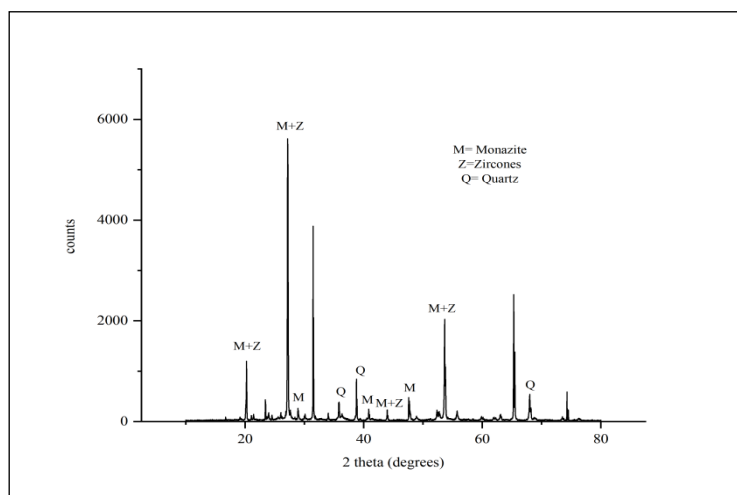


Fig. 19 XRD spectrum of sand samples from Chavara beach

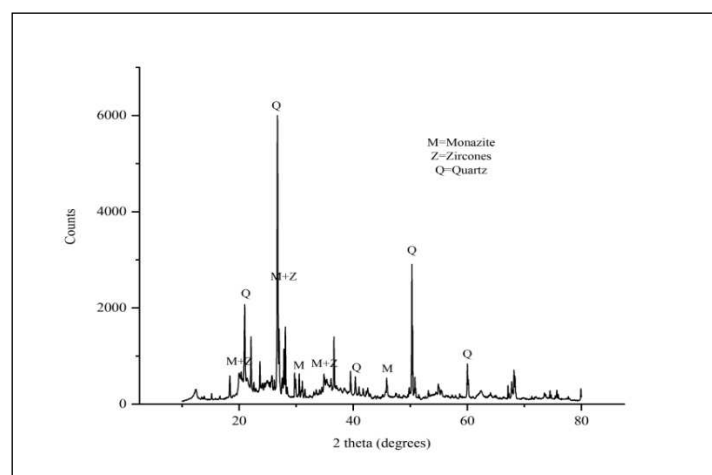


Fig. 20 XRD spectrum of the sand samples from the coastal regions of Kavalthottam

The Geographical settings behind the radionuclides distribution

The physiography, relief and geology of a place are very much associated with the geomorphic process that happened millions of years ago. The geomorphic processes include both endogenetic and exogenetic activities of nature, which carve the existing physiography of a place [52]. The geomorphic processes are induced by the tectonic activities triggering from the mantle region that comes out through fissures, and weaker areas of the earth's crust are stated as the endogenetic forces, which are the force behind landform evolution. The process is categorized and considered as catastrophic as well as diastrophic and is noted as hypogenous [53]. The hot molten magma, when it reaches the upper surface as lava, due to these hypogenous processes, becomes a storehouse of different minerals and metals.

This lava then solidifies to become a rock or related structure in situ. This occurs when the lava interacts with the atmosphere and gets cooler at different rates based on the climate, topography and location. This cooling of the lava at different rates creates different rocks [54]. The elements and components in the magma/lava then rearrange into different crystalline structures to form igneous rock. Cooling, hardening, and crystallization are the general processes in igneous rock formation. The rock is usually stated as the primary rock. Both sedimentary, which is formed from sediment lithification due to layer-by-layer deposition, then compression due to the weight of upper layers and cementation due to the compression and metamorphic rocks, which are formed due to changes in form or the composition in igneous and sedimentary rocks, are primarily evolved from the igneous rock [52].

The rocks form the parent of the soil, which is been mixed with different chemicals and biological contents and forms a well-developed soil. Nature never stops its act there. Due to the formation of rocks, the endogenetic force is considered a constructional process, but after the development of land or the rocks, nature then starts its destructive activities as exogenetic activities to ensure equilibrium [55]. The exogenetic force includes both degradational and aggradational work.

Weathering, erosion, transportation, and deposition are the major processes initiated by exogenetic forces to level up the irregularities generated during endogenetic activities. This force, through its continuous interaction with the developed or developing rocks, disintegrates or decays the rock through chemical, physical and biological weathering. The weathering process breaks the rocks into pieces and then fragments over the course of time [56]. These

pieces and fragmentation are then eroded and transported by the agents of gradation, such as wind, water, glaciers, seawater, etc.

The erosion process involves corrosion, attrition, hydraulic work, etc. The factors which support the process of transportation are gravity, slope and gradient, velocity and carrying capacity of the transporting agent and the weight of the load [57-58]. Wherever variation in the above factors happens, there will be a change in the quantity of the load carrying. The gravity remains almost the same throughout the earth, even though there are slight changes based on geographical factors. The gravitational pull of the weathered and eroded materials forms the most important mechanical process in the exogenetic process [57]. The increase in the slope will increase the velocity of the agent and intensify erosion and transportation.

The carrying capacity has also been influenced by the slope and gradient. The steeper slope with the increased size of the transporting agent will increase load-carrying capacity [59-60]. But when the load increases, this inversely affects the velocity. Thus, overload, along with the reduction of the slope, will force the transportation agent to drop its load wherever possible, and the process is known as deposition or sedimentation. The load, which is transported through flotation, solution, suspension, saltation and traction, is deposited in areas where they take deviation or shift the velocity to a lower gear. The geomorphic process makes the uplifted land through endogenic activities into a pediplain or peneplain with the support of exogenetic agents [55]. The geomorphic process reaches its entropy at this stage; however, the process will not stop; it is the beginning of a new upliftment as the entire process is cyclic in nature. The process as a whole is termed a cycle of erosion.

About 65 to 66 million years ago, the formation of the Western Ghats, one of the largest escarpments in the world, occurred [61]. The supercontinent Gondwana land was separated, and India started moving away from the Seychelles microcontinent [62]. Due to this divergent movement of the Indian plate, the escarpment, present Western Ghats was formed at the plate boundary. This tectonic activity, which was causing the rifting of the Indian plate, also induced the magmatic underplating process, where the hot molten rocks started accumulating under the plate. Due to the thermal effect of this hot material, the crust becomes thinner, and buoyancy becomes relatively higher, which further pushes the plate upward. The process is part of endogenetic activity, where the upliftment of the crust, including the escarpment (Western Ghats) to rise above 1000 meters. This upliftment has resulted in the rise of a steep cliff rising from the coastal plain of western India [63].

The Deccan Volcanic eruptions also contributed to the present structure of the Western Ghats [64]. The lava that came out from the volcanoes later cooled and solidified to form a thick layer of basaltic surface east of the region. On the western side, the thermal collapse resulted in the cooling, contracting and sinking of the land. This causes the area to subside under the sea. Thus, creating an elevated land east of the Western Ghats and subsided coastal area west of the Western Ghats. The multiple rifting episodes, along with the lateral variation in the crustal thickness, especially on the western coast of India, are considered the main reason behind the formation of the Western Ghats [65-66].

To follow the statement that most of the deposits on the western side of the Western Ghats are up to the coastal area, the slope factor and the exogenetic forces ensure the same is understood clearly. The physiography of Kerala divides its land into three classes: the highland in the east (Western Ghats region) with an average height above 75m, the midland regions with undulating hills and valleys with height averages between 7.5m to 75 m and the low land region with a height below 7.5m up to sea level in the western post side [39]. This shows a general slope of the land from east to west throughout Kerala. This physiography facilitates the flow of rivers from the Western Ghats to the Arabian Sea in the same direction. The 44 rivers create a network of water flow covering all the regions of the midland and lowland with an annual yield of 703000mm³ of water [39].

As stated in the study, the rivers are one of the important agents of gradation. They have the capacity to carry large volumes of sediments from the Western Ghats region to its downward stream channels and distribute them in all the low-elevated regions. The materials or the sediments carried by the river depend upon the place through which the river flows and the parent rock from where they are collecting the sediments. The process of erosion, transportation and deposition continues till they reach the Arabian Sea, but in varying intensity. In general, erosion is more prominent in the Western Ghats region, and deposition is more prominent in the coastal regions due to the gradient character of the land. The midland that forms the transition zone has characteristics of both erosion and deposition.

The understanding of the process will be completed by clearing the concept of watershed and drainage basin. Geographical studies usually divide its geographical space based on the boundary of watersheds or river basins. Like the 44 rivers in Kerala, each one of the rivers holds its own geographical boundary as its drainage basin. So, the geographical area of Kerala can be calculated as the sum of the area of all these drainage basins. The sediments

or the eroded material carried by each of these rivers also do not go beyond its watershed area till it reaches the sea. The watershed is hence described as a hydrological unit in which water enters the region and will leave only through a single outlet.

“A watershed defines the boundaries of a system of hydrologically connected people, places, and things; the activities at every point in a watershed impact all points downstream and are impacted by activities at all points upstream” [67]. The watershed or the river basin thus controls all the material coming under its boundary [68]. The sediments and eroded particles from the upper catchment area of a river will only be redistributed inside its watershed area. The maximum deposition is seen at the mouth of the river, which is the exit point of the watershed; this is mainly due to the reduced gradient. In Kerala, these exit points are mostly seen at the river mouth, which in turn is the coastal area.

From the detailed understanding of the geological and geographical setting of Kerala, it can be summarized that the Western Ghats region, which is formed as a result of endogenetic force and through Magmatism, has a rich deposition of Charnockite and related rocks. This Charnockite rock is in sufficient presence with Monazite. The large-scale rain, along with the influence of other weathering agents, erodes the parent rock. This is being transported by the major rivers of Kerala under the influence of slope and gravity, whereas in Kerala, a general slope is from the east to the west. The basin boundary of the rivers and watersheds of their tributaries helps the materials to concentrate at the single outlet, which is considered as the estuary region (the river mouth). The geographical study considers the Monazite as sediment here, which is taken from the Western Ghats and deposited at the river mouth.

The sediments deposited at the river mouth should be redistributed to the coastal beaches; the duty is assigned to the sea waves. Sea waves are waves of different wavelengths that move among and through each other. They are, however, travelling in different directions as well [69]. The sea waves are the product of wind motion, where wind energy is transferred to water [70]. The wind can control the direction, velocity and intensity of the waves. These sea waves are a strong agent of gradation in the coastal areas. They have the power to erode, transport and deposit materials coming under their influence. The depositional characteristics include the material carried from the deep sea, coastal landforms and the headland by the river [71].

In the Kerala scenario, the material (Monazite) carried by the rivers up to the mouth region is redistributed to its coastal beaches by the sea waves. The deposition of these materials

by the sea waves is influenced by the direction of waves and the velocity of the waves, which is highly influenced by the wind blowing above it. Studies have shown that the wave direction on the Kerala coast is dominated in the south-west direction with variations of 15-20 degrees north or south. The south west monsoon season has greater effect on it [72-74]. Thus, based on the wind and wave direction, it can be assumed that the maximum deposition happens at the northern coastal beach side of the river mouth [8].

To geographically study the distribution and causes of activity concentration of radioactive elements in the Kollam coastal region, samples of beach sand were collected from thirteen points in the district (Table 29). The Kollam district is always famous for the presence of radioactive elements and their concentration. The Kollam coastal region shows a very high level of activity concentration in the sample study as well. A detailed geographical study has been conducted to understand the reason behind the concentration rate at each point.

The sample collected from Paravoor Beach comes under the Ayirur watershed, a small watershed with most of the highland covered by Charnockite rock. The Pozhikkara and Mayyanad come under the Ithikkara watershed. Here, the Paravoor Lake near the beach is drained by the Ithikkara River. The river carries radioactive elements from the Velloor region and Mannoor region, where two extensions of Charnockite rocks are mapped. As a result of this geomorphological process both regions show high concentrations of radioactivity

The Kollam beach region like other coastal regions in Kollam district shows high concentration of radioactivity. The specific samples were collected from the southern side of Kollam district, which is adjacent to the Kollam Canal, leading from the south extension of Ashtamudi Lake. The lake has very high concentration of radioactive elements as the major river draining the lake, the Kallada River, coming from a region extensively covered by Charnockite rock. This includes places like Edamon, Thenmala, Aryankavu, Punnala, and Kalanjoor. The concentration value may become high if the samples have been collected from the Kollam harbor. The spatial distribution of mean activity concentration of natural radionuclides such as ^{40}K , ^{226}Ra and ^{232}Th in the collected sand samples is given in Fig. 21.

Table 29. Mean activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th in the coastal areas of Kollam district

Sampling locations	Mean activity concentrations (Bqkg^{-1})		
	^{40}K	^{226}Ra	^{232}Th
Paravoor	334±3	863±6	4269±8
Pozhikkara	160±10	460±19	1624±202
Mayyanad	300±30	828±32	1847±245
Kollam Beach	172±11	563±10	2232±181
Neendakara harbour	164±10	540±8	994±29
Chavara	679±205	2350±390	20146±2944
Kavilthottam	76±5	426±25	938±128
Kattil Beach	661±154	1016±178	6852±1340
Vellanamthuruth	144± 9	272±38	887±20
Alappad viewpoint	143±20	530±51	1907±26
Parayakadavu	582±7	816±21	2423±404
Azheekal South	232±33	740±14	1870±619
Azheekal	178±38	654±108	2193±64
Indian average value	400	29	64
World average value	420	33	45

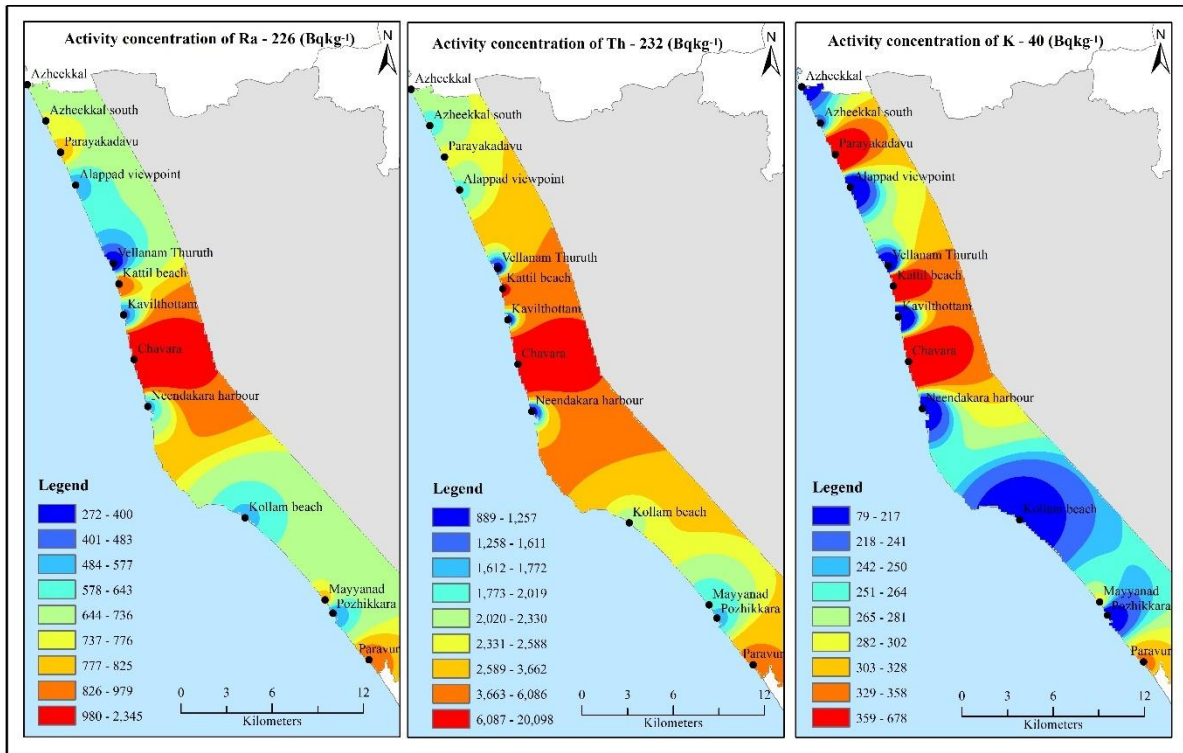


Fig. 21 Spatial distribution of the mean activity concentration of ^{40}K , ^{226}Ra and ^{232}Th in the sand samples collected from the coastal belt of Kollam

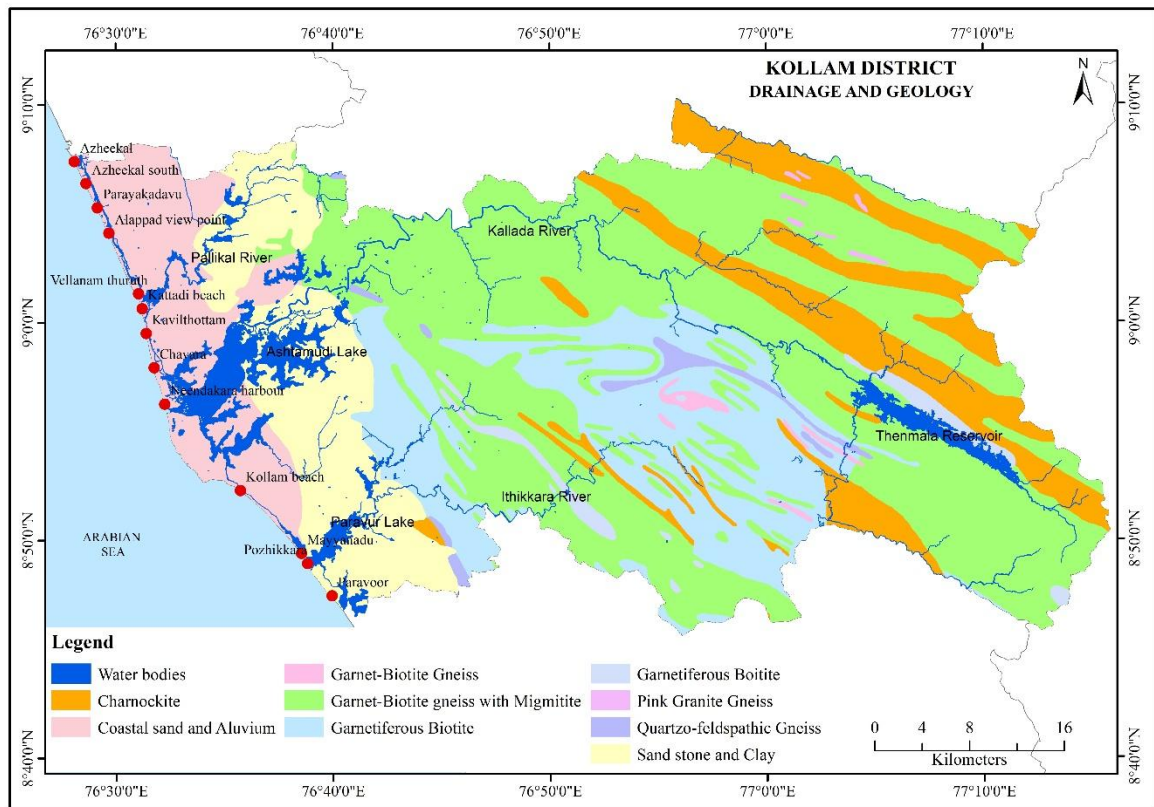


Fig. 22 Drainage and Lithology map of Kollam district

Neendakara harbor and Chavara coasts lie in the same watershed region of Kollam Beach, Kallada. As the Chavara region lies to the North of the watershed, it has a more favourable geography for very high concentrations. The region records the highest concentrations of ^{232}Th , ^{226}Ra , and ^{40}K . Even though Neendakara has the same favourable conditions, the presence of the harbor at the river mouth reduces the option of deposition at the closer beaches here. Kattil Beach, Kavilthottam, Alappad viewpoint, Parayakadavu, Azheekal South and Azheekal region come linearly from Chavara to the groyne of Valiyazeekal. The groyne acts as a barrier to the further movement of sediments, thus depositing all the sediments in these regions. An almost uniform distribution of activity concentration is visible in the Alappad viewpoint, Parayakadavu, Azheekal south and Azheekal region due to the same. However, the Kavilthottam beach shows a reduced amount of radionuclides due to the presence of mining field of Indian Rare Earths Limited (Fig. 22).

The comparison of activity concentration of radionuclides with other regions of the World is given in Table 30. The comparison study shows that the activity concentration of radionuclides obtained from the present investigation is comparable with the values reported in other regions of the World.

Table 30. Comparison activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th with other regions of the World

Region	^{40}K (Bqkg ⁻¹)	^{226}Ra (Bqkg ⁻¹)	^{232}Th (Bqkg ⁻¹)	Reference
Kollam coastal region	69-998	244-2968	789-25548	Present study
Kanyakumari coast	360	75	565	[75]
Kollam Beach	35.9–735.7	49.8–1070.8	177.2–9014.2	[8]
Kovalam Beach	234	414	2245	[9]
Varkala	47.31–4827.2	32.3–1021.6	313.01–9437.12	[11]
Karnataka, India	278.2-650.7	22.5-90.58	20.4-136.3	[76]
Chhatrapur, Orissa	120	230	2500	[4]
Kalpakkam	324–405	36-258	352–3872	[3]
Chavara	1116	-	23029	[77]
Indian average value	400	400	64	[50]
World average value	420	420	45	[50]

Conclusion

The systematic analysis of geographical processes controlling the monazite placer depositions along the coastal belt of Kollam district have been conducted in the present investigation. The geographical process is the key deciding factor in the distribution of sediments around the world and various endogenetic and exogenetic processes play a vital role in deciding the chemical, biological and physical composition of the contents in the sediments. Thus, the concentrations of the radionuclides and the presence of monazite minerals vary according to geological and geographical factors. The charnockite rocks in the Western Ghats region hold a large amount of monazite minerals or radioactive elements. The lithology and drainage of Kollam district reveals that, the rivers coming or running through, or having the presence of these rocks in its catchment, carry the radioactive elements and deposits at the lower catchment regions and river mouths of the Kollam district. Moreover, due to the effect of the southwest monsoon, the materials deposited by the rivers in its mouth have been mainly transported to its northern beaches, making the region a highly concentrated. These findings of the study will provide insights for effective exploration and management of monazite resources in the coastal belt of Kollam district, southwest coast of India.

Acknowledgement

The first author wishes to acknowledge Kannur University for providing financial support as Junior Research Fellowship for the successful completion of this research work. Additionally, sincere gratitude is extended to Directorate of Research, Wadiahuda Institute of Research & Advanced Studies (WIRAS), Vilayancode, Kannur, for providing the necessary facilities for the cartographic analysis.

Competing Interests

The authors declare that there are no competing interests.

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