Applied Radiation and Isotopes 85 (2014) 1–10

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Role of light and heavy minerals on natural radioactivity level of high background radiation area, Kerala, India

V. Ramasamy [a,*], M. Sundarrajan [b,c], G. Suresh [d], K. Paramasivam [a], V. Meenakshisundaram [e]

[a] Department of Physics, Annamalai University, Tamilnadu, India
[b] Department of Physics, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Enathur, Kanchipuram, Tamilnadu, India
[c] Department of Physics, Manonmaniam Sundaranar University, Tirunelveli, Tamilnadu, India
[d] Department of Physics, Arulmigu Meenakshi Amman College of Engineering, Vadamavandal (Near Kanchipuram), Tamilnadu, India
[e] Former Head, Health and Safety Division, IGCAR, Kalpakkam, Tamilnadu, India

HIGHLIGHTS

- Due to the higher activity concentrations, the present sediments pose significant radiological threat to the peoples.
- Light mineral characterization shows the presence of eight light minerals.
- Heavy mineral separation analysis revealed the presence of nine heavy minerals.
- Multivariate statistical analysis gives an idea about the role of mineralogy on radionuclide concentrations.
- Along with clay content, the heavy minerals induce the ^{238}U and ^{232}Th concentrations and light mineral calcite controls the ^{40}K concentration.

ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form
18 October 2013
Accepted 28 November 2013
Available online 6 December 2013

Keywords:
Beach sediments
Natural radionuclides
Minerals
Statistical analysis

ABSTRACT

Natural radionuclides (^{238}U, ^{232}Th and ^{40}K) concentrations and eight different radiological parameters have been analyzed for the beach sediments of Kerala with an aim of evaluating the radiation hazards. Activity concentrations (^{238}U and ^{232}Th) and all the radiological parameters in most of the sites have higher values than recommended values. The Kerala beach sediments pose significant radiological threat to the people living in the area and tourists going to the beaches for recreation or to the sailors and fishermen involved in their activities in the study area. In order to know the light mineral characterization of the present sediments, mineralogical analysis has been carried out using Fourier transform infrared (FTIR) spectroscopic technique. The eight different minerals are identified and they are characterized. Among the various observed minerals, the minerals such as quartz, microcline feldspar, kaolinite and calcite are major minerals. The relative distribution of major minerals is determined by calculating extinction co-efficient and the values show that the amount of quartz is higher than calcite and much higher than microcline feldspar. Crystallinity index is calculated to know the crystalline nature of quartz present in the sediments. Heavy mineral separation analysis has been carried out to know the total heavy mineral (THM) percentage. This analysis revealed the presence of nine heavy minerals. The minerals such as monazite, zircon, magnetite and illmenite are predominant. Due to the rapid and extreme changes occur in highly dynamic environments of sandy beaches, quantities of major light and heavy minerals are widely varied from site to site. Granulometric analysis shows that the sand is major content. Multivariate statistical (Pearson correlation, cluster and factor) analysis has been carried out to know the effect of mineralogy on radionuclide concentrations. The present study concluded that heavy minerals induce the ^{238}U and ^{232}Th concentrations. Whereas, light mineral (calcite) controls the ^{40}K concentration. In addition to the heavy minerals, clay content also induces the important radioactive variables.

1. Introduction

Minerals are the composite of different elements and occur naturally as crystalline inorganic substances in sediments. Mineral sediments, sands and mud are weathered from mountain belts, transported by rivers, glaciers or wind and deposited at the coast. Minerals are classified into two types on the basis of its density such as light minerals (specific density less than 2.9×10^3 kg m^{-3}) and heavy minerals (specific density greater than 2.9×10^3 kg m^{-3}) (de Meijer et al., 2001). The distribution and characterization of light minerals in beach sediments have persuaded by many geoscientists and studied them with respect to depositional environment and provenance (Cherian et al., 2004). Extensive beach sand deposits are

* Corresponding author. Tel.: +4144 222488.
E-mail addresses: drgsphy@gmail.com, srsaranram@rediffmail.com (V. Ramasamy).

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http://dx.doi.org/10.1016/j.apradiso.2013.11.119

located along the coastal lines of the eastern and the western parts of India. Out of the total world deposit of about 2500 million ton, India has a share of about 10–11% i.e. about 275 million ton (Siddiqui et al., 2000). Beach sand deposits are the major source of beach sand minerals, commonly known as Heavy Minerals. Mineralogical characterization comprises two main parameters namely mineral assemblage and chemical composition of mineral groups or even individual mineral grains. The composition of mineral assemblages is related to the mineralogical composition of the source region and also related several other processes such as physical sorting, mechanical abrasion and dissolution. Physical sorting is a result of hydrodynamic conditions during transport and depositional stages. It controls both absolute and relative abundance of minerals. Mechanical abrasion takes place during transport and cause grains to diminish in size by a combination of fracturing and rounding. Dissolution causes partial and complete loss of minerals in a variety of geochemical conditions at several stages in the sedimentation cycle. Mineralogical properties of beach sand reflect the geological history of the original rock formation (Carvalho et al., 2011).

Many areas in the world such as Australia, Brazil, China, India, Iran, Japan, etc., possess high levels of natural radiation. In the recent years, studies on the high background radiation areas in the world have been of prime importance for risk estimation due to long-term low-level whole body exposures to the public. Southwest coast of India is known since long as one of the high level background radiation areas in the world. Natural radiation levels in the region are higher than normal which are believed to be emitted from the rich deposits of the monazite bearing beach sand. The mineral monazite contains radioactive elements, which is the main cause for natural radiation in the southwest coast belt (Singh et al., 2007).

In the process of mineral formations, the radionuclides are incorporated as trace elements in their crystal lattice. Later on and through erosive processes, these minerals are transported and can reach the coast becoming part of the sediments (Ligero et al., 2001). According to Carvalho et al. (2011), most of the uranium and thorium atoms are bound in dark colored accessory minerals known as heavy minerals. However, thorium (by adsorption) and potassium (chemical composition) are associated with clay minerals. They also stated that the light minerals such as quartz and feldspar may contain relatively high concentrations of ^{40}K. Hence, based on the above discussions, accumulation and distribution of radionuclides depend mostly on the characteristics (types and abundance) of the light and heavy minerals.

Kerala is the most densely populated state in India and about 80% of peoples are living in the coastal zone. The state Kerala has the coastal length about 560 km which covers about 15% of the state's total area of 38,863 sq km. The major renewable resources available along this coastal zone are water, agriculture and fisheries and non-renewable resource such as placer minerals, soils, sub fossil deposits, etc. Kerala is endowed with a rich diversity of marine fishes with a numerical strength of more than 300. The Chavara coast of Kerala is well known place for rich heavy mineral deposits. Most of the industrial and commercial establishments in Kerala have been concentrated in the coastal zone (Ramasamy et al., 2013). Therefore, radioactivity level of the coastal region of Kerala (beaches) in relation to light and heavy minerals are essential to know the mineralogical effect on natural radiation level.

We have published the spatial distribution of radionuclides and their radiological hazardous nature of the Kerala beach sediments in our Applied Radiation and Isotopes journal (Ramasamy et al., 2013). In that article, it is concluded that the light and heavy minerals may be played a role in different sampling sites and hence the present study. In the present study, role of light and heavy minerals on natural radiation level of the beach sediments is focused. For this, core radioactivity data and their discussion were taken from Ramasamy et al. (2013) to correlate them with the mineralogical data. Hence, the main goal of this study is to: (i) analyze the mineralogical (light and heavy) characterization of the beach sediments of Kerala, India, (ii) calculate extinction coefficient and crystallinity index in order to know the relative distribution of major minerals and crystalline nature of quartz respectively, (iii) know the percentage of sand, silt and clay by granulometric analysis and finally (iv) assess the role of mineralogy on natural radiation level of the beach sediment using multivariate statistical analysis.

2. Materials and methods

2.1. Study area

Kerala has ten coastal districts. The present study area covers four coastal districts such as Ernakulam, Alappuzha, Kollam and Trivandrum (9° 57′ 49″; 76° 14′ 16″–8° 34′ 21″; 76° 50′ 9″). Nearly 45% of coastal region was covered by the present study. The surficial sediments of the continental shelf and slope of Kerala can be divided into terrigenous, biogenous and chemogenous sediments. In the shelf and slope of Kerala, terrigenous sediments mostly occur as sands in the near shore (up to 10–12 m water depth) followed by a zone of silty clays on the inner shelf. An admixture of abundant terrigenous and biogenic constituents carpets the outer shelf. Around 1.33 crores peoples are living in the present study area. Other importances of study area were presented in Ramasamy et al. (2013).

2.2. Sample collection

The present study area covers a total length of about 200 km, from which 39 successive locations were selected and numbered as S_1-S_{39} (Fig. 1). The sample locations were recorded in terms of degree – minute – second (latitudinal and longitudinal position) using a hand-held global positioning system (GPS) (Model: GARMIN GPS-12) unit. Each location is separated by a distance of approximately 4–5 km. The samples were collected from 5–10 m away from the high tide at the depth of 0–5 cm, when it makes towards the road side. Samples were collected by plastic spade during summer period of 2011 and collected samples were packed in polyethylene bags. Each sample has the weight of about 3 kg. The collected samples were air dried at room temperature in open air.

2.3. Radioactivity measurements

Details of sample preparation, and instrument used and procedure for radioactivity measurement (gamma ray spectrometer) were clearly presented in Ramasamy et al. (2013). The below detectable limit (BDL) of the each radionuclide is 5.5 Bq/kg for ^{238}U and ^{232}Th and 21.5 Bq/kg for ^{40}K.

2.4. Mineralogical study

2.4.1. Characterization of light minerals

2.4.1.1. Sample preparation and instrument used. Wet grinding was carried out by placing 30–50 mg of the sample in an agate mortar along with 20–25 drops of ethanol. The ground samples were dried in an hot air oven at 110 °C to remove the moisture content and sieved to 53 μm grain size. Using the KBr pellet technique, the sample was mixed with KBr at various ratios viz., 1:10, 1:20, 1:30, 1:40 and 1:50. The mixture was then pressed into a transparent disc in dye at sufficiently high pressure. The samples in the ratio 1:30 was taken for further analysis, since it gives rise to maximum transmittance and observable peaks (Ramasamy et al., 2011). Using the Perkin-Elmer RX1 FTIR spectrometer, the infrared spectra for all sediment samples were