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Function of minerals in the natural radioactivity level of Vaigai River sediments, Tamilnadu, India – Spectroscopical approach

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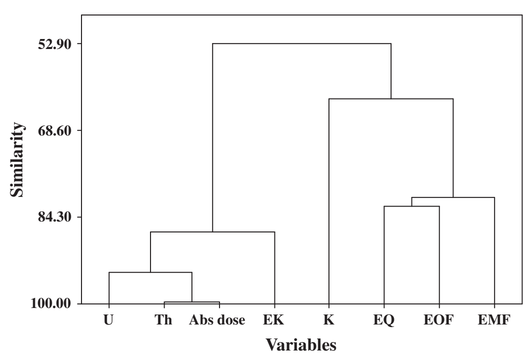
HIGHLIGHTS

- Vaigai River radioactivity level and mineralogy studied by spectroscopic techniques.
- Some sites are having higher radioactivity values than the recommended safety limit.
- Relative distributions of minerals are studied by extinction coefficient calculation.
- Crystallinity index calculation shows the presence of well ordered crystalline quartz.
- The kaolinite has a great influence on radionuclides concentrations in river sediment.

GRAPHICAL ABSTRACT

Dendrogram shows cluster of variables. Cluster I shows that the total radioactivity mainly depends upon concentration of ^{238}U and ^{232}Th and content of kaolinite. The cluster III shows that the other major minerals are not significant for the total radioactivity.



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ABSTRACT

Using Gamma ray and Fourier Transform Infrared (FTIR) spectroscopic techniques, level of natural radioactivity (^{238}U, ^{232}Th and ^{40}K) and mineralogical characterization of Vaigai River sediments have been analyzed with the view of evaluating the radiation risk and its relation to available minerals. Different radiological parameters are calculated to know the entire radiological characterization. The average of activity concentrations and all radiological parameters are lower than the recommended safety limit. However, some sites are having higher radioactivity values than the safety limit. From the FTIR spectroscopic technique, the minerals such as quartz, microcline feldspar, orthoclase feldspar, kaolinite, gibbsite, calcite, montmorillonite and organic carbon are identified and they are characterized. The extinction coefficient values are calculated to know the relative distribution of major minerals such as quartz, microcline feldspar, orthoclase feldspar and kaolinite. The calculated values indicate that the amount of quartz is higher than orthoclase feldspar, microcline feldspar and much higher than kaolinite. Crystallinity index is calculated to know the crystalline nature of quartz and the result indicates that the presence of ordered crystalline quartz in the present sediment. The role of minerals in the level of radioactivity is assessed by multivariate statistical analysis (Pearson's correlation and Cluster analysis). The statistical analysis confirms that the clay mineral kaolinite is the major factor than other major minerals to induce the important radioactivity variables such as absorbed dose rate and concentrations of ^{232}Th and ^{238}U.

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Introduction

Natural radioactivity is mainly produced from the radioactive decay of potassium (^{40}K), uranium (^{238}U) and thorium (^{232}Th). Another minor source is the radioactive decay of the ^{235}U isotope, but it is very rare in the earth's crust [1]. Everyone on the planet is exposed to some background level of radiation and it exists in various geological formations like soils, sediments, rocks, plants, sand, water and air [2]. Hence, humans should be aware of their natural environment with regard to the radiation health effects. Continuous exposure to even low level radiation may adversely affect the human health. Exposure to ionizing radiation can damage living organisms and cause health effects in humans, including leukaemia and other cancers [3].

Generally, sediments are composition of minerals which are produced through weathering and erosion of rocks. Minerals are the composite of different elements and occur naturally as crystalline inorganic substances in sediments. River sediments are mineral depositions formed through weathering and erosion of either igneous or metamorphic rocks. The depositions are basically composed of clastic materials. Especially, these depositions on the bottom of rivers consist of sand and gravel particles of different sizes which are particularly valuable for the building construction. 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 river and coast becoming part of the sediments [4]. Hence, the accumulation and distribution of radionuclides depend mostly on the characteristics (types and abundance) of the minerals.

The investigation of solids by the absorption of infrared rays has attracted considerable interest in the recent years. The new generation of infrared spectrometers based on the Michelson interferometer and known as Fourier Transform Infrared (FTIR) spectrometer, has significant advantages over dispersive instruments in terms of sensitivity, resolution and wave number accuracy [5]. These advantages make FTIR particularly suitable for the study of minerals when used in conjunction with other techniques and it contains information about the mineralogy [2]. It is used by mineralogists and sedimentary petrologists for mineralogical applications. The Infrared spectra of river sediments from Cauvery, Vellar and Ponnaiyar river have been effectively characterized using FTIR by Ramasamy et al. [2,6,7]. Ko and Chu [8] had effectively studied the red soils from Taiwan by some spectroscopic techniques including FTIR. Recently, mineralogical characterization of polluted soils from South India was assessed using FTIR by Oumabady Alias Cannane et al. [9]. Ramasamy et al. [2] studied the mineral characterization of Ponnaiyar river sediment and they reported that kaolinite acts as the major role than other minerals to increase the level of radioactivity in the Ponnaiyar river sediments. Also, El-Gamal et al. [10] had reported that the mineralogical structure of the sediments is one of the controlling factors for level of radioactivity in river sediments.

Hence, the intend of the present study is to (i) determine the level of natural radioactivity and the mineral characterization of the sediments of Vaigai river (importance are discussed elsewhere), Tamilnadu, India. (ii) Calculate ten different radiological parameters to know the complete radiological characterization and their effect. (iii) Calculate the extinction coefficient and crystallinity index to know the relative distribution of major minerals and crystalline nature of quartz respectively. (iv) Assess the responsibility of minerals to the fixation of level of radioactivity in the sediment using multivariate statistical analysis.

Materials and methods

Study area

In the present study, sediment samples were collected from various sites of the Vaigai river. It is originated on the Varushanadu hills in Theni district and terminated at Ramnad district of Tamilnadu state in Bay of Bengal. It covers five districts (Theni, Dindigul, Madurai, Sivagangai and Ramnad) in Tamilnadu. Vaigai dam was constructed across the river nearer to Andipatti, Theni District. Capacity of the dam is nearly 172 M.Cu.metre. It provides water for irrigation to the Madurai and Dindigul districts as well as drinking water to Madurai and Andipatti. The sediments of this river are excavated only for building constructions. Many hydraulic structures, barrages and river control structures were established in this river for irrigation, drinking water and control purpose respectively. However, the places which are around the Vaigai river have experienced intense developments in agriculture, industry, tourism, transport and urbanization. The discharge of wastes and toxic metals from above establishments and living residents are directly let out into the river. In the view of agriculture, overuse of chemical fertilizers and pesticides from these lands are washed into the river. For transport purpose, more number of bridges were constructed and some new bridges are under construction across the river. These are all main external factors in the study area.

Sample collection

The present study area (Vaigai river) covers from Varushanad hills (Theni) (Lat: 9°44′30″N; Long: 77°30′52″E) to Athangarai (Palk Strait) of Ramnad (Lat: 9°20′45″N; Long: 78°59′59″E), which covers an area about 240 km, from which 40 successive locations were selected and numbered as S_1–S_{40} (Fig. 1). Each sampling location is separated by a distance of 5–6 km approximately. All sediment samples were collected at 0–10 cm depth during the summer season (April–May 2011). Each sample has a weight of 3–4 kg approximately. The collected samples were dried at room temperature in an open air for two days and stored in black polythene bags. The exact position of each sampling site was recorded using hand held GARMIN GPS meter (Global Positioning System, Model No. 12).

Radioactivity measurements

Sample preparation

The collected samples were homogenized and oven dried at 110 °C for 24 h. The samples were then packed and sealed in an impermeable air tight 250 ml PVC container (9 cm × 6.5 cm: Height × Diameter) to prevent the escape of radiogenic gases of radon (^{222}Rn) and thoron (^{220}Rn). About 450–500 g of samples were used for measurements. Before measurements, the containers were kept sealed hermetically for about four weeks in order to reach equilibrium of ^{238}U, ^{232}Th and their decay products. The exact net weight of the samples was determined before counting [2].

Instrument used and procedure

Samples were subjected to gamma spectral analysis using high-resolution gamma ray spectrometry system consisting of coaxial *p*-type HPGe detector for the measurement of ^{238}U, ^{232}Th and ^{40}K concentrations in sediment samples. To reduce the contribution considerably from background radiation in the laboratory, the samples were kept in lead shield having a shielding efficiency of 95% while recording the spectrum. It was shielded by 15 cm thick lead on all four side and 10 cm thick on top. The concentrations of various radionuclides of interest were determined using the counting spectra of each sample by APTEC MCA software. The