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Horizontal and vertical characterization of radionuclides and minerals in river sediments

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ABSTRACT

The natural radionuclide (^{238}U, ^{232}Th and ^{40}K) contents and mineral characteristics have been analyzed for the different depth sediment samples of Ponnaiyar River with an aim of evaluating the radiation hazard and its relation to specific minerals. To know the complete radiological characteristics, the radiological indices have been calculated and compared with recommended values. In an FTIR study, the extinction coefficient and crystallinity index is calculated to find the relative distribution of major minerals and the crystallinity of quartz, respectively. Both horizontal and vertical distributions of radionuclides and major minerals are studied. Multivariate statistical analyses (cluster and factor) were carried out to determine the relationship between the radioactivity and the minerals. Statistical analyses suggest that the kaolinite is the major mineral to increase the level of radioactivity in the river sediments.

1. Introduction

Everyone on the planet is exposed to some background level of radiation. Human exposure to ionizing radiation is one of the scientific subjects that attracts public attention, since radiation of natural origin is responsible for most of the total radiation exposure of the human population (UNSCEAR, 2000). Natural radioactivity is widespread in the earth's environment and it exists in various geological formations like soils, rocks, plants, sand, water and air. Hence, humans should be aware of their natural environment with regard to the radiation effects due to the naturally occurring and induced radioactive elements. The long-term exposure to uranium and radium through inhalation has several health effects such as chronic lung diseases, acute leucopoenia, anemia and necrosis of the mouth. Radium causes bone, cranial and nasal tumours. Thorium exposure can cause lung, pancreas, hepatic, bone, kidney cancers and leukemia (Taskin et al., 2009). Knowledge about the distribution of radioactivity present in natural materials enables one to assess any possible radiological hazard to mankind by the use of such materials.

Among the various building materials, river sediment (sand) is one of the most important and major mixing materials for building construction in India, especially in Tamilnadu (state). In addition to being the main source of continuous radiation exposure to humans, sediment acts as a medium of migration for the transfer of radionuclides to biological systems. Natural radionuclides in river sediment generate a significant component of the background radiation exposure of the population (Degerlier et al., 2008). Therefore, the knowledge of the concentrations and distributions of the natural radionuclides in the river sediments are of great interest since it provides useful information for monitoring environmental contamination and associated human health by natural radioactivity.

Most natural solids are minerals. River sediments are not an exception. They are detrital products of rocks and bear the mineralogical properties of the original rock formation. The principal constituents of most of the sediments are quartz, feldspar, carbonates and clay minerals. Of these, quartz is overwhelmingly the most abundant. Feldspar, though more abundant in parent igneous rock, is of intermediate durability and so is less abundant than quartz in sediments. The other minerals, though more durable than feldspar, are simply less abundant in source material (Dott and Batten, 1976). The mineralogical properties of sediments reflect the geological history of transport and sorting processes. 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) spectrometers, have significant advantages over dispersive instruments in terms of sensitivity, resolution and wave number accuracy (Fysh and Fredericks, 1983).

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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 (Ramasamy et al., 2006b). It is used by mineralogists and sedimentary petrologists for mineralogical applications. The Infrared spectra of river sediments from Cauvery and Vellar have been characterized by Ramasamy et al. (2005 and 2009).

Ponnaiyar, an interstate river, is one of the largest rivers of Tamilnadu state, India. The river has supported many civilizations of peninsular India throughout history and continues to play a vital role in supplying precious water for drinking, irrigation and industry to the people of the Indian states of Karnataka, Tamilnadu and Pondicherry. (TN). Sathanur dam is 226 km from the origin of the river. The river flows through Villupuram and Cuddalore districts for about 160 km, 35 km in the Thiruvannamalai district and finally terminates in the Bay of Bengal near Cuddalore. The sediments of this river are excavated only for building construction. On both the banks of this river, many residents and some industries (textile, paint and hollow brick manufacturing) are situated.

Hence, the intent of this study is to: (i) determine the natural radiation level and analyze the mineral characteristics in both horizontal and vertical profiles of the sediment of Ponnaiyar River, Tamilnadu, India. (ii) Calculate the radiological parameters and extinction coefficient of major minerals in order to know the complete radiological characteristics of the sediments and relative distribution of major minerals, respectively. (iii) Assess the relationship between the radioactivity and the relative distribution of major minerals using multivariate statistical analyses.

2. Material and methods

2.1. Study area

The present study area covers from Sathanur dam (longitude 78°51′10″E and latitude 12°4′48″N) to Cuddalore (termination point of the river) (longitude 79°47′685″E and latitude 11°45′350″N) about 200 km and including the three districts, Thiruvannamalai, Villupuram and Cuddalore, of Tamilnadu (Fig. 1). Ponnaiyar river originates from the South-Eastern slope of Nandidrug hills in Karnataka state with flowing distance of 430 km from its point of origin to the sea. The river area is predominantly built up with granite and gneisses rocks of archean period. The granite is of very good quality and extensive out crops and masses of it are commonly found. The chief components of rocks are hornblende and feldspar. Foliation is seldom seen. In the plains of reserve forest, quartz is found. The diamond granite is also found in scattered pockets in the areas of Chitteri hills (Dharmapuri and Krishnagiri sub-divisions). Charnokite rocks of archean period are also seen in some area. At the tail end of the basin, pockets of sand stone, clays pebble of tertiary period and limestones of cretaceous period are found.

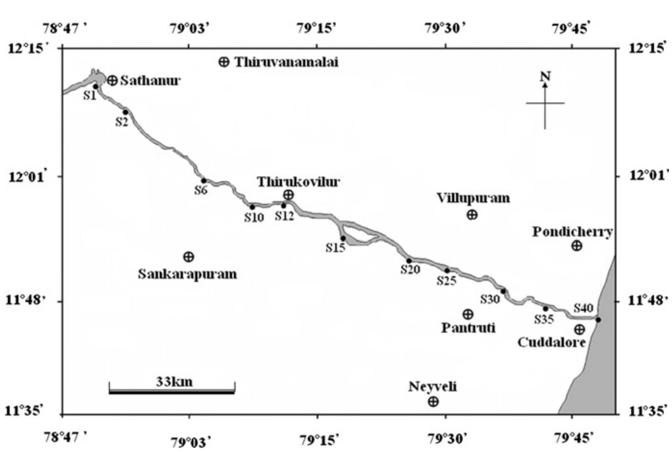

Fig. 1. Location of Ponnaiyar river with their experimental sites in Tamilnadu.

2.2. Sample collection

The present study area (Ponnaiyar river) covers a total length of 200 km, from which 40 successive locations were selected and numbered S_1–S_{40}. 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 recently deposited sediment samples were manually collected with the help of a plastic spade in polyethylene bags during the period March–April 2008 from three layers (upper surface: 0–5 cm, first foot: 30 cm and second foot: 60 cm) of the river. Each sample has the weight of about 4 kg. The collected samples were air dried at room temperature in open air.

2.3. Radioactivity measurements

2.3.1. 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 the ^{238}U, ^{232}Th and their decay products. The exact net weight of the samples was determined before counting.

2.3.2. Instrument used and procedure

Using a high-resolution NaI (Tl) detector gamma spectrometry system, the activity concentration of primordial radionuclides ^{238}U, ^{232}Th and ^{40}K in sediment samples was measured. The detector (NaI (Tl) crystal) has size of 3 in. × 3 in. The resolution of the detector was 7.5%. It was shielded by 15 cm thick lead on all four sides and 10 cm thick on top. To reduce the contribution considerably from background radiation in the laboratory, the samples were kept in a lead shield having a shielding efficiency of 95% while recording the spectrum. The output of the detector is analyzed using an 8 K multichannel analyzer (TNI PCA II Ortec model).

The concentrations of various radionuclides of interest were determined using the counting spectra of each sample. The peaks corresponding to 1.46 MeV (^{40}K), 1.76 MeV (^{214}Bi) and 2.614 MeV (^{208}Tl) were considered in evaluating the activity levels of ^{40}K, ^{238}U series and ^{232}Th series, respectively.

Standard sources of natural uranium (1997.56 Bq), natural thorium (1237.28 Bq) and KCl (5181.59 Bq) with a standard 250 ml container from International Atomic Energy Agency (IAEA) were used for calibrating the gamma ray spectrometer. All the samples were counted for a period of 10 000 s and the spectra were analyzed for the photo-peak of uranium, thorium daughter products and ^{40}K. Three IAEA standard reference materials (a standard soil of known radioactivity, soil-6; a uranium ore sample, RGU1 and a thorium ore sample, RGTh1) were also used for checking the calibration of the system. The below detectable limit (BDL) of each radionuclide is determined from the background radiation spectrum for the same counting time as for