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A relationship between the natural radioactivity and mineralogical composition of the Ponnaiyar river sediments, India

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ABSTRACT

The natural radiation level has been determined for the sediment samples of Ponnaiyar River, India with an aim of evaluating the radiation hazard. The average activity concentrations are within the world and Indian average values although some extreme values have been determined. The magnetic susceptibility measurement has been carried out to know the magnetization nature of the sediments. More downstream (mouth) of the river has quite higher magnetic susceptibility values. The mineralogical characterizations of the sediments have been carried out using Fourier Transform Infrared (FTIR) spectroscopic and XRD technique. The minerals such as quartz, microcline feldspar, orthoclase feldspar, kaolinite, calcite, gibbsite, montmorillonite, smectite, palygorskite and organic carbon are identified from FTIR analysis. Few minerals like zircon, monazite and hornblende are identified only in XRD analysis. The relative distribution of major minerals is determined by calculating extinction coefficient. The calculated values show that the amount of quartz is greater than microcline feldspar and very much greater than kaolinite in all the sites. The content of quartz and microcline feldspar is decreases, and kaolinite gradually increases towards the river mouth. Multivariate Statistical analyses were carried out between the parameters obtained from radioactivity analysis and other analyses to know the existing relations. Obtained results are discussed and suggested that the natural radioactivity level of the present sediments is mainly controlled by clay content and lesser extent to magnetic susceptibility.

1. Introduction

Natural radioactivity is widespread in the earth's environment and it exists in various geological formations like soils, rocks, plants, sand, water and air. Human exposure to ionizing radiation is one of the scientific subjects that attract public attention, since radiation of natural origin is responsible for most of the total radiation exposure of the human population (UNSCEAR, 2000). Everyone on the planet is exposed to some background level of radiation. Hence, human should be aware of their natural environment with regard to the radiation effects due to the naturally occurring radioactive elements. Knowledge about the distribution of the radioactivity present in natural materials enables one to assess any possible radiological hazard to mankind by the use of such materials. Radiation exposures due to naturally occurring radionuclides in sediments including river sediments (building materials) have been studied by many workers (El-Arabi et al., 2006; Narayana et al., 2007; El-Gamal et al., 2007; Powell et al., 2007; Krmar et al., 2009; Al-Hamarneh and Awadallah, 2009; Ramasamy et al., 2004, 2006a and Taskin et al., 2009) all around the world. They were reported that the all studied values are lower than the recommended values.

River sediments are detrital products of rocks and bear the mineralogical properties of the original rock formation. 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 human, sediment acts as a medium of migration for transfer of radionuclides to the biological systems and hence, it is the basic indicator of radiological contamination in the environment. 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

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radionuclides in the river sediments are of great interest since it provides useful information in monitoring of environmental contamination and associated human health by natural radioactivity. The long-term exposure to uranium and radium through inhalation has several health effects as chronic lung diseases, acute leucopoenia, anemia and necrosis of the mouth. Radium causes bone, cranial, and nasal tumors. Thorium exposure can cause lung, pancreas, hepatic, bone, kidney cancers and leukemia (Taskin et al., 2009). Therefore, gamma dose rates and radionuclides activity concentrations in river sediments should be monitored.

The mass-specific magnetic susceptibility (χ) indicates the amount of magnetic particles in materials like soil, sediments or rocks. Magnetite is of particular importance because of its high χ value ($5–10 \times 10^{-8}$ m^3/kg) and its widespread occurrence in nature. It can be found in many different kinds of rocks, modern soils and sediments. Magnetic particle can originate from weathered bed rocks, biogenic activity, volcanic ashes or extraterrestrial particles (Knab et al., 2006). The spatial and temporal distribution of χ in the sediments is not only due to variable abundance of iron-bearing ferri and anti-ferromagnetic minerals, but also due to the presence of diamagnetic and paramagnetic minerals such as quartz, feldspar, carbonates and clays (Pattan et al., 2008). Mineral magnetic measurements have been widely used for delineating the environmental pollution during the recent decades, because they are fast, cost-effective, non-destructive and sensitive (Yang et al., 2007). Magnetic susceptibility of the river sediments mostly depends on ferromagnetic mineral concentration. These minerals have origin by disintegration of parent rocks during the pedogenesis, by lithogenic process and by anthropogenic activities.

Most natural solids are minerals. Sediments are not exemption. These 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 runs second place to quartz in sediments. The others, though more durable than feldspar, are simply for less abundant in source materials. The mineralogical properties of sediments reflect the geological history of transport and sorting process. 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. These advantages make FTIR particularly suitable for the study of minerals when used in conjunction with other techniques and it contain 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, 2009).

River sediments are usually composed of silicate, fine grains of minerals with high cation exchange capacity (CEC) such as clay and other minerals. In the process of mineral formation, the radionuclides are incorporated as trace elements in the crystal lattice. The concentration of these elements depends on the type of mineral and abundance in the parent magma. Later on and through erosive processes, these minerals are transported and can reach the river and coast becoming part of the sediments (Ligero et al., 2001). In case both mineral and radionuclide can be assumed to be dispersedly present and similar affected by the process, correlation between the major minerals and the radionuclides may be expected.

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 the both banks of this river, many residents and some industries (textile, paint and hollow brick manufacturing) are situated.

Hence, the objective of this study is to: (i) analyze the natural radiation level, magnetic susceptibility and mineral characteristics of the sediments of Ponnaiyar River, Tamilnadu, India, (ii) calculate the radiological parameters and extinction coefficient in order to know the complete radiological characteristics of the sediments and relative distribution of major minerals respectively and (iii) know the existing relation between the radioactivity and mineral characteristics using statistical analysis.

2. Materials 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 three districts namely Thiruvannamalai, Villupuram and Cuddalore districts 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.

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 as S_1 to S_{40}. The sample location were recorded in terms of degree - minute - second (Latitudinal and Longitudinal position) using hand-held Global Positioning System (GPS) (Model: GARMIN GPS-12) unit. Each location is separated by a distance of 4–5 km approximately. The recently deposited sediment samples were manually collected with the help of a plastic spade in polyethylene bags during the period (March–April 2009) from upper surface (0–5 cm) of the river. 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

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 radon (^{222}Rn) and thoron (^{220}Rn). About 450 to 500 g of samples were used for measurements. Before measurements, the containers were kept sealed hermetically and externally about four weeks in order to