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Natural radioactivity levels in topsoil from the Pearl River Delta Zone, Guangdong, China

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ABSTRACT

Concentrations of the natural radionuclides ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K have been measured by γ-ray spectrometry in 796 topsoil samples from the Pearl River Delta Zone (PRDZ) of Guangdong, China. The mean concentrations for ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K were found to be 140 ± 37 Bq kg^{-1}, 134 ± 41 Bq kg^{-1}, 187 ± 80 Bq kg^{-1} and 680 ± 203 Bq kg^{-1} dry mass, respectively. These values were all higher than the mean values in soil for China and the world. Outdoor air-absorbed dose rates, calculated from activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, ranged from 86 to 237 nGy h^{-1}, with a mean value of 165 ± 46 nGy h^{-1}. The corresponding annual outdoor effective dose rate per person was estimated to be between 0.11 and 0.29 mSv y^{-1}, with a mean value of 0.20 ± 0.06 mSv y^{-1}, which was also higher than the world mean value of 0.07 mSv y^{-1}. The radium equivalent activity (Ra_{eq}) and the external hazard index (I_r) resulted from the natural radionuclides in soil, were also calculated and found to vary from 230 to 676 Bq kg^{-1} and from 0.6 to 1.8, respectively. The Ra_{eq} and the I_r in all the investigated regions were up to 75% higher than the set limits of 370 Bq kg^{-1} and 1.0, respectively.

1. Introduction

The two prominent natural sources of external radiation to which human are exposed are cosmic rays and terrestrial gamma-rays. Terrestrial gamma-rays are mainly derived from radionuclides belonging to ^{238}U and ^{232}Th series and ^{40}K that are present in the earth's crust (UNSCEAR, 2000; Obed et al., 2005; Murty and Karunakara, 2008; Psichoudaki and Papaefthymiou, 2008). Distributions of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in soils depend on the radionuclide distribution in rocks from which they originate and on the processes through which the soils are concentrated. Higher radiation levels are generally associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. The specific levels of terrestrial background radiation are related to the types of rocks from which the soils originate (UNSCEAR, 2000). Therefore, the natural environmental radiation mainly depends on geological and geographical conditions (El-Shershaby, 2002; Tzortzis et al., 2003; Baykara and Doğru, 2009).

The Pearl River Delta Zone (PRDZ) of Guangdong province, comprising of many cities such as Guangzhou, Shenzhen, Zhuhai and others, is located between longitudes 112°00′ and 115°24′ and latitudes 21°43′ and 23°56′, covering a total area of about 41,700 km^2 (Fig. 1). The PRDZ is one of the China's most developed areas, accounting for about 20% of the China's Gross Domestic Product (GDP).

However, many regions in Guangdong province are known to be high background radiation (HBR) areas, such as Yangjiang (HBRRGC, 1980; Wei and Sugahara, 2000) and Zhuhai (Tan et al., 1991; Pan, 2001). The high natural radionuclides concentrations in top soils are common in the areas because of base rocks rich in natural radionuclides. For example, in Yangjiang of China, the elevated radiation levels are found from monazite sand deposits, which have thorium in high concentration (UNSCEAR, 2000). The central base rocks in the PRDZ include granitic and schistic rocks, and the igneous rocks of granitic composition are enriched in thorium and uranium.

According to the large-scale geological investigation data (Guangdong Geologic Survey Institute: Maps of geochemistry for U, Th and K in the PRDZ. Inner data), high concentrations of natural radionuclides (^{238}U and ^{232}Th) have been found in granite in the PRDZ. But there is a lack of data concerning soil radioactivity in the PRDZ, especially in the populous areas. Thus, the radiation level in the areas needs to be assessed to address growing public concern. In order to produce representative data, a field campaign for soil radioactivity assessment has been conducted in the year 2007–2008. The aim of this work is to study ^{238}U, ^{226}Ra, ^{232}Th and

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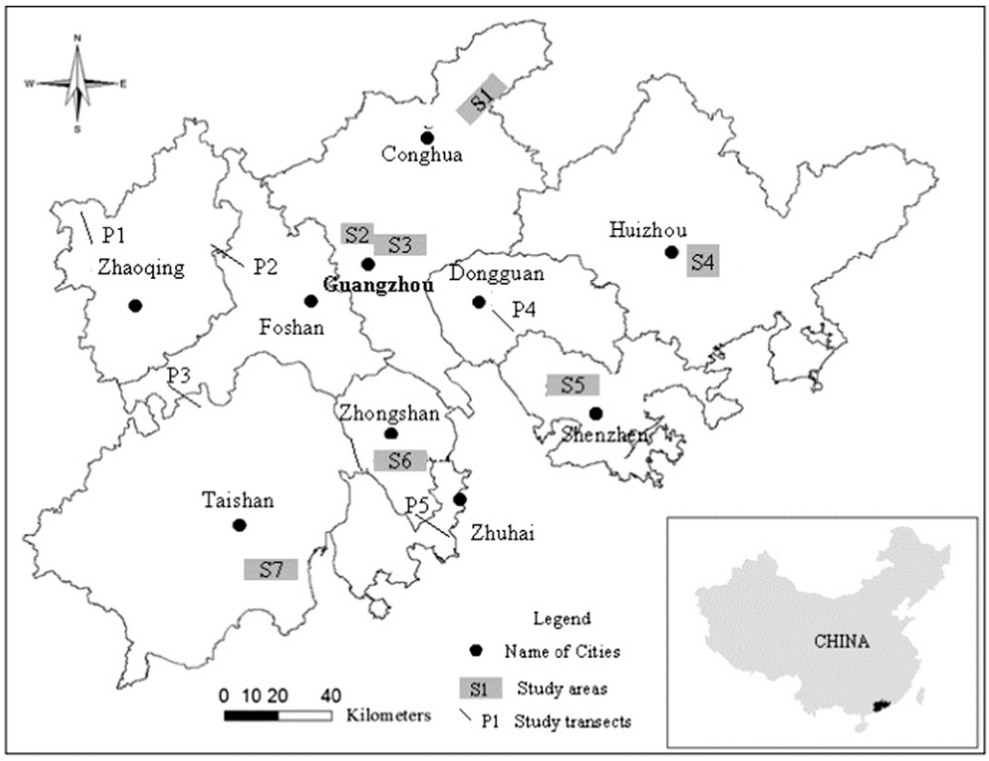

Fig. 1. Study areas in the Pearl River Delta Zone of Guangdong, China. S1–S7 are the sampling regions, P1–P5 are the measurement transects.

^{40}K radioactivity concentrations in soils collected from the PRDZ. The absorbed dose rates in outdoor air were calculated to obtain the mean annual effective dose to the population in the areas. Also, the Ra_{eq}, the I_r and the $^{226}Ra/^{238}U$ ratios were calculated.

2. Materials and methods

2.1. Sample collection

According to radionuclide concentration in rock reported in the map of the inner data, the investigated regions were divided into seven research areas and five geological transects. The transects covered the higher uranium and thorium background areas and areas of relatively lower radioactivity. Other factors such as the stratum, lithological character and population distribution of the regions were also considered. The sampling locations are given in Fig. 1. Each research area is approximately 10 km × 20 km in size and each transect is approximately 10 km in length. The sampling was done from the open areas available in timbered mountainous regions, hillside lands and cultivated lands. The surveyed area was divided into a 1.5 km × 1.5 km grid, and soil samples were collected from the points of intersections. Due to steep gradients, some points on transects could not be sampled directly, and samples were taken from a position as close as possible (100–150 m). A Global Positioning System (GPS, GARMIN, eTrex type) was used to determine geographical coordinates. The sample sites were marked and the soil samples from 0 to 30 cm depth were collected after carefully removing litter and plant roots from surface. In total, the 796 soil samples were collected for the analysis of the natural radioactivity.

2.2. Sample treatment

After collecting the samples, they were treated following standard procedures (GB/T 11743-89, 1989). The soils sample was well mixed after removing extraneous materials such as roots, stones and gravel. The soil aggregates were broken down and then the sample was spread on polythene sheets in stainless steel trays. The sample was dried in an oven at 110 °C for 48 h until the sample weight became constant. The dried soil sample was then pulverized to a particle size of ≤0.25 mm mesh. The sample was stored in an air-tight cylindrical polythene container (70 mm × 75 mm) and kept for a minimum period of 4 weeks to allow ^{226}Ra to come into equilibrium with its short-lived progenies. The container was completely filled to allow uniform distribution of ^{220}Rn and ^{222}Rn progenies in the sample and to avoid any accumulation in a residual surface air layer.

2.3. Radioactivity measurement

The activity concentrations of the natural radionuclides ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in soil samples were determined by direct γ-ray spectrometry using a Canberra HPGe detector, with a relative efficiency of 30% and an energy resolution of 1.8 keV for ^{60}Co γ-ray energy line at 1332 keV. The detector was enclosed in a graded lead shield (Model 747, Canberra, USA). The detector was connected to the DSA-1000 (Canberra, USA) for data acquisition and the spectrum was analyzed by GENIE-2000 software. The energy calibration was performed using the standard reference radionuclide sources: ^{60}Co, ^{137}Cs and ^{152}Eu, while the efficiency calibration was performed using the reference soils (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) obtained from the National Institute of Metrology of China (NIMC) in the appropriate matrix. The standard soil samples were packed into the same type containers for the target samples, and measured.

The activity of ^{40}K was directly determined using the 1460.8 keV photopeak. For ^{232}Th, the photopeaks of ^{212}Pb (238.6 keV), ^{208}Tl (583.1 keV) and ^{228}Ac (911.1 keV) were used. The ^{238}U concentration was derived from the weighted mean of the photopeaks of ^{234}Th (63.5 and 92.6 keV), and the ^{226}Ra concentration was derived