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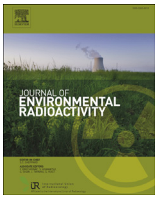

A survey of natural terrestrial and airborne radionuclides in moss samples from the peninsular Thailand

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ABSTRACT

The aim of this study was to determine the activity concentrations of natural terrestrial radionuclides (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) and airborne radionuclides (^{210}Pb, ^{210}Pb$_{ex}$ and ^{7}Be) in natural terrestrial mosses. The collected moss samples (46) representing 17 species were collected from 17 sampling localities in the National Parks and Wildlife Sanctuaries of Thailand, situated in the mountainous areas between the northern and the southern ends of peninsular Thailand (~7–12 °N, 99–102 °E). Activity concentrations of radionuclides in the samples were measured using a low background gamma spectrometer. The results revealed non-uniform spatial distributions of all the radionuclides in the study area. Principal component analysis and cluster analysis revealed two distinct origins for the studied radionuclides, and furthermore, the Pearson correlations were strong within ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K as well as within ^{210}Pb and ^{210}Pb$_{ex}$, but there was no significant correlation between these two groups. Also ^{7}Be was uncorrelated to the others, as expected due to different origins of the airborne and terrestrial radionuclides. The radionuclide activities of moss samples varied by moss species, topography, geology, and meteorology of each sampling area. The observed abnormally high concentrations of some radionuclides probably indicate that the concentrations of airborne and terrestrial radionuclides in moss samples were directly related to local geological features of the sampling site, or that high levels of ^{7}Be were most probably linked with topography and regional NE monsoonal winds from mainland China.

1. Introduction

The terrestrial radionuclides, ^{40}K, ^{232}Th, and ^{238}U, originate from crustal materials in the soil dust and can be detected in mosses. Global average activities of ^{40}K, ^{232}Th and ^{238}U in soil are around 400, 35 and 30 Bq/kg, respectively (UNSCEAR, 2000). The contents of these radionuclides in the environment depend on the geological setting (McCartney et al., 2000). These radionuclides can be transported and removed from the atmosphere by dry or wet deposition of dust particles (Karunakara et al., 2003; Dragović and Mandić, 2010; Krmar et al., 2007). The presence of terrestrial radionuclides in atmosphere (as well as in biota) is affected by a number of factors, mainly related to the emission of dust particles, such as ash from coal-fired power plants, fossil fuel combustion, phosphate fertilizers, and phosphate manufacturing plants (Belivermiş and Çotuk, 2010). On the other hand, artificial radionuclides such as ^{137}Cs are associated with nuclear fission and released into the environment by atmospheric deposition, which varies by geographical location and precipitation (Ritchie et al., 1990).

The airborne radionuclides ^{7}Be and ^{210}Pb originate in various ways. Beryllium-7 is produced by spallation reactions of galactic cosmic rays with nitrogen-14, oxygen-16 and carbon-12 in the lower stratosphere and the upper troposphere. The amount of ^{7}Be in the atmosphere depends on the galactic cosmic ray flux, proton flux from the sun during solar events, stratosphere-troposphere exchange, and meteorological parameters affecting transportation of aerosols in ground level air (Petrova et al., 2009). Lead-210 is a progeny from the decay of ^{222}Rn in the ^{238}U decay chains. Its concentration in surface air depends mainly on the rate of emanation of ^{222}Rn and on local meteorological parameters. After release to atmosphere with aerosol particles, ^{210}Pb returns to the earth surface by washout and by sedimentation (Uğur et al., 2003).

The interest in mosses as bio-monitors has rapidly increased since the work of Jenkins and coworkers (1972), who reported the activity concentrations of some radionuclides in mosses collected

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from the Olympic National Park, Washington, U.S.A. (Jenkins et al., 1972), and after the use of mosses in biomonitoring of heavy metals in European countries (Rühling and Tyler, 1973). The use of terrestrial mosses in detection of radionuclides over large areas has been reported, for example for around 100 km along the coast in Syrian mountains (Al-Masri et al., 2005), for over 400 km along an international freeway in Serbia (Krmar et al., 2007), and for over 67,000 km^2 in the Marmara region, Turkey (Belivermiş and Çotuk, 2010). These publications demonstrated the high potential of moss sampling, suggesting that biomonitors can be used in monitoring radionuclide deposition over large areas, provided adequate number and density of sampling locations.

It is well-known that terrestrial mosses grow in various climate zones in the forests. Mosses have no well-developed root system, and the nutrients for growth are directly taken from the air via precipitation or by dry deposition. Their accumulation capacity of airborne elements is higher than that of other vascular plants growing in the same habitats (Aleksiayenak et al., 2013). Furthermore, their morphologies do not vary with the seasons, so they can retain and accumulate pollutants throughout the whole year (Szczepaniak and Biziuk, 2003). Mosses have been widely used in the field of radiology as monitors of radionuclides in the environment, for example in (i) a uranium mine (Pettersson et al., 1988), (ii) a lignite center (Tsikritzis, 2005), (iii) areas near nuclear and coal-fired power plants (Sumerling, 1984; Delfanti et al., 1999; Karunakara et al., 2003; Uğur et al., 2003; Sert et al., 2011), and (iv) the monitoring of ^{137}Cs in many European countries after the Chernobyl nuclear accident (Kirchner and Daillant, 2002; Dragović and Mihailović, 2009; Krmar et al., 2007).

Although the moss sampling technique is widely used, there are no prior reports of using mosses for natural radioactivity measurements in Thailand, with the exception of a pilot study in 2011, which focused on Hatyai City, a regional center of Southern Thailand in Songkhla province (Krmar et al., 2013). The current study is the first to attempt at utilizing Thai mosses as bio-monitors of radionuclides over a large area of peninsular Thailand.

The objectives of this work were to measure the activity concentrations of radionuclides in moss samples collected from peninsular Thailand, to assess/explain the spatial distributions and correlations of the activity concentrations of radionuclides, and to analyze probable factors affecting those distributions.

2. Materials and methods

2.1. Geography, meteorology, and geology of the sampling area

Peninsular Thailand is located between latitude 7–12 °N and longitude 99–102 °E) and covers around 70,715 km^2 area. The longest distance from the northern end to the southern end is about 750 km. It is located north of the Malay Peninsula and is geographically separated into two parts by a number of high mountain ridges laid in the center along the north to south direction that affect the climate of these parts (Fig. 1 (a)). The eastern side of the Thai peninsular is wet, with highest precipitation during November to February because of the NE monsoon, with cold air mass transported from the Chinese mainland and marine air masses from the Gulf of Thailand. This area is warm and dry in the summer season from March to June, but it often rains even in this relatively dry period due to depressions or typhoons. In contrast, the west side of the peninsula is affected by the SW monsoon from the Indian Ocean to the Andaman Sea carrying mainly marine air masses. High precipitation from June to October makes the climate on the west side considerably different from that on the east side (Wangwongchai et al., 2005; Tipayamongkholgul et al., 2009).

In the geologic setting, peninsular Thailand has two parts called the middle and the southern peninsula (Bunopas, 1981; Bhongsuwan, 1993), as shown in Fig. 1(b). The geology of the west side of middle peninsula is dominated by Permo – Carboniferous rock (Paleozoic sedimentary rock), which consists of mudstones and sandstones. Samples W04, W06 and W08 were collected from this part. Along the mountain areas from north to south, Mesozoic granite intrudes into Paleozoic sedimentary rock and is surrounded by narrow metamorphic aureoles. Samples W05 and W07 were collected from this area. On the east side of the peninsula, Quaternary sediments have deposited on the valley floor and the coastal area, from which samples E09 were collected. This area is surrounded by cultivated areas. There are two major active faults called Khlong Marui Fault (KMF) and Ranong Fault (RF). The KMF lies in NE direction from Changwat Phung Nga (sample W05) to Suratthani, and the RF extends from Changwat Phung Nga to Ranong. Samples W07 and W08 were collected from the RF fault zone.

The southern peninsula extends south – eastward from Changwat Krabi and Changwat Suratthani to south of Changwat Songkhla and Changwat Narathiwat (near the Malaysian border). It has a number of granite mountain lines from north to south in the middle part of the peninsula and continues into the Gulf of Thailand, where the Mesozoic granites are exposed and there are several basins of Cenozoic coal-bearing beds. Four of our sampling sites are located in the mountain forests in Changwat Suratthani (E10), Changwat Nakorn Sithammarat (E11, E12) and Changwat Phathalung (E13) near the Mesozoic granite exposure. In the mountain ranges extending from north to south between Changwat Nakorn Sithammarat and Changwat Satun, Mesozoic granite intrudes into Paleozoic sedimentary rocks (Ordovician limestone) at the places where sampling sites W01, W02, E13, W14 – W16 are located. Only site W03 is located in a cultivated area in Changwat Trang, where Mesozoic sedimentary rocks are exposed on the ground surface. At Changwat Songkhla, Paleozoic sedimentary rock (Carboniferous shale) is exposed at the northern part of Ko Yo, and extends southward into the north-western part of the Malay Peninsula; the sampling site E17 is located in this area.

2.2. Sample preparation and measurement

The 46 moss samples from 17 locations in peninsular Thailand were collected in March 2012. The sampling locations are presented in Fig. 1(a). The sampling sites W01 – W02, W04 – W06, W08, E12 – E13, and W14 – W18 are located in mountainous areas of the National Parks and Wildlife Sanctuaries. These sites are remote from human activities and industrial zones. Sampling sites W03, W08, E10 and E17 are located near cultivated areas and villages.

Sites W01 – W08 and W14 – W16 are geographically on the west side of the Peninsula, while E09 – E13 and E17 are on the east side. At the time of sampling moss the peninsula faced the NE monsoon coming from the Chinese continent and from the South China Sea.

It is noted that in this study a variety of moss species were collected at each site, because it is difficult to collect a specific moss species from all the different sampling sites. The list of moss species sampled is presented in Table 1. At most sites the moss samples were collected in areas near water (small streams) with the exceptions of sites E11 – 2, E11 – 3, E11 – 4, E12, and W16. In these study areas the air moisture is probably an important factor with large amounts of water droplets continuously absorbed onto the bryophytes. This factor probably affects the radionuclide contents in the moss samples as well. Samples E12 – 1 to E12 – 4 were collected from topsoil at the top of a mountain (Khao Ram Rome) about 1000 m above mean sea level.