

## Specific Activity and Radioactive Contour Maps of Natural ( $^{40}\text{K}$ , $^{226}\text{Ra}$ and $^{232}\text{Th}$ ) and Anthropogenic ( $^{137}\text{Cs}$ ) Radionuclides in Surface Soil Samples from Phang Nga Province, Thailand

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**Abstract** The specific activity of the natural ( $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) and anthropogenic ( $^{137}\text{Cs}$ ) radionuclides have been studied and evaluated for 97 surface soil samples collected from 7 districts of Phang Nga province in the south of Thailand. High-purity germanium (HPGe) detector and gamma ray spectrometry analysis system were employed to measure and analyze the experimental results. It was found that, the ranges of specific activities of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  in surface soil samples are 251.50 – 15740.34, 15.21 – 791.42, 18.14 – 854.34 and < 0.33 – 16.91 Bq/kg with average values are  $2886.77 \pm 225.93$ ,  $165.71 \pm 8.45$ ,  $160.36 \pm 7.93$  and  $5.76 \pm 2.49$  Bq/kg, respectively. The results were also compared with some research data in national and global radioactivity measurement and evaluations. Furthermore, the radiological hazards of Phang Nga province were calculated through the radium equivalent activity ( $Ra_{eq}$ ), the external hazard index ( $H_{ex}$ ), the gamma absorbed dose rate (D) and the annual effective dose rate ( $AED_{out}$ ) and also compared with research data in the south of Thailand and the safety limits recommended values by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Moreover, the radioactive contour maps of the natural ( $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) and anthropogenic ( $^{137}\text{Cs}$ ) radionuclides have been also created for the investigated area.

### Introduction

Naturally Occurring Radioactive Material (NORM) and Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) activities which have been accumulated in the earth environment, were one of the interesting issues in the past decade. Enhanced levels of NORM may be associated with certain natural materials, minerals and other resources. Exploitation of these resources and production of consumer items may lead to further enhancement of the radioactivity in the products, by-products, residues or waste arising from the industrial process. Furthermore, human activities that exploit these resources may lead to significantly enhanced concentrations of TENORM [1]. Since the southern region of Thailand contains one of most extensive tin belt of the world many provinces in southern part of Thailand certainly have the experiences of NORM activity e.g. tin mining, dressing and smelting. In this paper, we will focus on Phang Nga province which is one of the richest tin provinces in the south of Thailand. According to the geology of Phang Nga province which is characterized by granites emplaced with the sedimentary and metamorphic rocks as shown in Fig. 1. Basically, granite rock is actually rather radioactive and has 5 to 20 times the concentration of uranium compared to other common rock types [2]. Nonetheless, Mesozoic granites of Peninsular Thailand contain large amounts of radioactive elements, uranium and thorium and are related to tin and tungsten mineralization [1]. Consequently, the activity of tin dressing and refining during the past years which spread over the Phang Nga province areas may cause the enhancement of the environmental dose rate due to NORM. Furthermore, anthropogenic radionuclides such as  $^{134}\text{Cs}$ ,  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{241}\text{Am}$  and  $^{239}\text{Pu}$  are also found in nature as a result of nuclear atmospheric weapons testing and nuclear accidents (e.g. Chernobyl and most recently Fukushima). However, dust particles contaminated by anthropomorphic  $^{137}\text{Cs}$  may become airborne

and inhalation of contaminated dust can result in an internal exposure [3]. For this reason, Phang Nga province was chosen as the studying areas to measure the specific activity of the natural ( $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) and anthropogenic ( $^{137}\text{Cs}$ ) radionuclides in surface soil samples and to study the radiological hazards in this location. Moreover, radioactive contour maps (RCM) of natural ( $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) and anthropogenic ( $^{137}\text{Cs}$ ) radionuclides in the investigated area, were also constructed and examined.

### Materials and Methods

97 surface soil samples were collected from 7 districts of Phang Nga province (except in Kao Yao district) in the south of Thailand. A map of Phang Nga province and sampling locations is shown in Fig. 2. The specific activities of natural ( $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) and anthropogenic ( $^{137}\text{Cs}$ ) radionuclides in all surface soil samples were determined by employing a high-purity germanium detector (HPGe, CANBERRA Model GC 2018) and gamma spectrometry analysis system. Geometric efficiency for surface soil matrices in the container was determined by KCl, IAEA/RGU-1, IAEA/RGTh-1 and IAEA/SL-2 reference materials (International Atomic Energy Agency IAEA, Vienna, Austria). The gamma energy spectra were analyzed using the program GENIE 2000. The specific activity of  $^{40}\text{K}$  was determined from its 1460 keV line. The specific activities of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  were determined by their decay products  $^{214}\text{Pb}$  (351.9 keV) and  $^{208}\text{Tl}$  (583.2 keV), respectively. The specific activity of  $^{137}\text{Cs}$  was also determined from its 661.7 keV line. Counting time interval was 10,800 s. The background spectrum was recorded immediately after or before the sample counting.

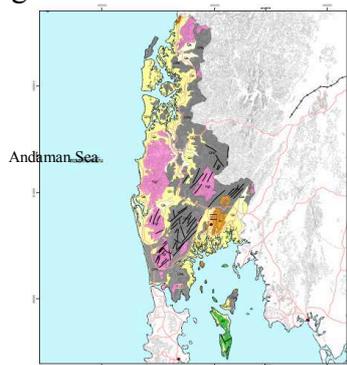


Fig. 1 The Geology of Phang Nga province [4]

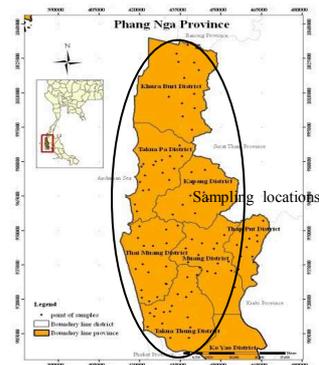


Fig. 2 Phang Nga province map and sampling locations

### Results and Discussion

Ranges and average values of specific activities of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  in 97 surface soil samples collected from Phang Nga province in the south of Thailand, were calculated and compared with some research data in the southern region of Thailand, OAP and global measurements and evaluations as shown in Table 1 and Table 2. Furthermore, the radiological hazards of Phang Nga province were also calculated through gamma absorbed dose rate (D)[5], radium equivalent activity ( $\text{Ra}_{\text{eq}}$ )[6], external hazard index ( $H_{\text{ex}}$ )[6] and annual effective dose rate ( $\text{AED}_{\text{out}}$ )[5] and also compared with research data in the south of Thailand and the safety limits recommended values by UNSCEAR which was shown in Table 3.

Table 1 Ranges and average value of specific activities of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  in 97 surface soil samples collected from Phang Nga province (Thailand).

Phang Nga Province (97 surface soil samples)	Specific Activities (Bq/kg)			
	$^{40}\text{K}$	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{137}\text{Cs}$
<b>Ranges</b>	251.50–15740.34	15.21–791.42	18.14–854.34	< 0.33 –16.91
<b>Average values</b>	$2886.77 \pm 225.93$	$165.71 \pm 8.45$	$160.36 \pm 7.93$	$5.76 \pm 2.49$

Table 2 Comparison of the average values of specific activities of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  in 97 surface soil samples collected from Phang Nga province (Thailand) with some research data in the southern region of Thailand, OAP and global measurements and evaluations.

Data Sources	Specific Activities (Bq/kg)			
	$^{40}\text{K}$	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{137}\text{Cs}$
Phuket Province [7]	4092.29 ± 267.05	<b>212.55 ± 10.18</b>	<b>203.98 ± 9.58</b>	5.91 ± 2.94
Krabi Province [8]	755.21 ± 112.25	69.11 ± 4.96	39.61 ± 3.91	2.96 ± 1.59
Satun Province [9]	4020.90 ± 246.55	98.75 ± 6.76	63.63 ± 2.34	<b>6.96 ± 2.61</b>
<b>Phang Nga Province</b> [present study]	2886.77 ± 225.93	165.71 ± 8.45	160.36 ± 7.93	5.76 ± 2.49
OAP Research Data [10]	511.04 ± 7.04	71.55 ± 3.13	211.19 ± 1.98	1.13 ± 0.49
<b>Worldwide Data</b>	420 <sup>a</sup>	35 <sup>a</sup>	30 <sup>a</sup>	3.7 - 37.0 <sup>b</sup>

<sup>a</sup> Data from [11], <sup>b</sup> Data from [12]

Table 3 Gamma absorbed dose rate (D), radium equivalent activity ( $\text{Ra}_{\text{eq}}$ ), external hazard index ( $\text{H}_{\text{ex}}$ ), and annual effective dose rate ( $\text{AED}_{\text{out}}$ ) of 97 surface soil samples collected from Phang Nga province (Thailand).

Locations	D (nGy/h)	$\text{Ra}_{\text{eq}}$ (Bq/kg)	$\text{H}_{\text{ex}}$	$\text{AED}_{\text{out}}$ (mSv/y)
Phuket Province [7]	<b>398.05</b>	<b>826.77</b>	<b>2.23</b>	<b>0.49</b>
Krabi Province [8]	88.34	185.09	0.50	0.11
Satun Province [9]	300.47	607.62	1.64	0.37
<b>Phang Nga Province</b> [present study]	295.81	617.31	1.67	0.36
UNSCEAR [11]	<b>55</b>	<b>370</b>	<b>1</b>	<b>0.48</b>

From Table 1 and Table 2, the ranges and average value of specific activities of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  measured in 97 surface soil samples of Phang Nga province are in the same ranges of the research data in the south of Thailand. The average levels of the  $^{40}\text{K}$  and  $^{226}\text{Ra}$  detected are 5.65 and 2.32 higher, respectively, and that of  $^{232}\text{Th}$  is 0.76 times than the OAP research data. The average levels of the  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  detected are 6.87, 4.73 and 5.35 times higher than the world average reported in UNSCEAR. The average value of the  $^{137}\text{Cs}$  is 5.1 times higher than the OAP research data and in the same range of the worldwide data. From the result in Table 3, all four radiological hazard indices for the investigated area are in the same range of research data in the south of Thailand. Furthermore, the gamma absorbed dose rate (D), the radium equivalent activity ( $\text{Ra}_{\text{eq}}$ ) and the external hazard index ( $\text{H}_{\text{ex}}$ ) are 5.38, 1.67 and 1.67 times higher, respectively, and that of the annual effective dose rate ( $\text{AED}_{\text{out}}$ ) is 0.75 times than the safety limits recommended values by UNSCEAR. Moreover, radioactive contour maps (RCM) of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  in Phang Nga province were constructed by using ArcGIS computer program and shown in Fig. 3.

### Summary

It was found that the range and the average values of specific activities of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{137}\text{Cs}$  in Phang Nga province are in the same range of research data in the south of Thailand but are always higher than the OAP research data and global measurements and evaluations. Hence, three calculated radiological hazard indices (D,  $\text{Ra}_{\text{eq}}$  and  $\text{H}_{\text{ex}}$ ) in this area were higher and that of the annual effective dose rate ( $\text{AED}_{\text{out}}$ ) was 0.75 times than the safety limits recommended values by UNSCEAR. It means that the concentration of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  in this area were rather high, especially in the northern and the western parts of the investigated area by considering the radioactive contour maps (RCM) in Fig.3. Furthermore, the concentration of  $^{137}\text{Cs}$  in Phang Nga province was in normal level. We can say that *the radiation hazard in Phang Nga province is significant to the population living in the investigated area.*

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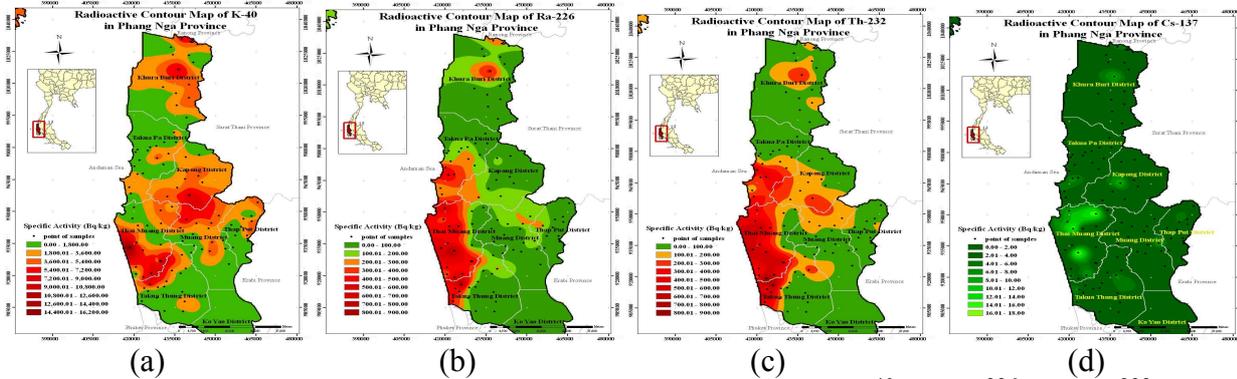


Fig. 3 Radioactive contour maps of specific activity values of (a)  $^{40}\text{K}$ , (b)  $^{226}\text{Ra}$ , (c)  $^{232}\text{Th}$  and (d)  $^{137}\text{Cs}$  in 97 surface soil samples collected from 7 districts in Phang Nga province, Thailand.

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