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Radioactivity determination of ^{137}Cs, ^{226}Ra, and ^{232}Th in beach she-oak (*Casuarina equisetifolia*) bark samples collected from Thailand's coastal regions

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ABSTRACT: Tree bark can serve as a biological indicator for the contamination of radioactive materials through atmospheric absorption. The key objective of this study is to evaluate the activity concentration of radioactive substances in beach she-oak bark as a biomonitor for radioactive contamination. The bark samples in 19 provinces along Thailand's coast were collected and analyzed using a high-purity germanium detector and gamma spectrometry system. The results show that the bark sample contained no detectable levels of ^{137}Cs radioactivity, implying no contamination of artificial radiation from historical nuclear power plant accident or man-made sources. The activity concentration of ^{226}Ra varied in the range of 1.30 ± 0.30 to 8.5 ± 0.8 Bq/kg, with an arithmetic mean of 3.8 ± 0.5 Bq/kg, while the concentration is in the range of 2.6 ± 0.6 to 15.1 ± 1.9 Bq/kg, with an arithmetic mean of 7.8 ± 1.4 Bq/kg, for ^{232}Th. The variation of activities observed in the higher ($> 9°$ N) and lower latitude ($< 9°$ N) regions could be influenced by the weather and rainfall amounts, which would lead to the accumulation of these nuclides. Notably, the highest ^{226}Ra and ^{232}Th concentration values were observed in the samples from Phuket and Phang Nga Province, respectively. We believe that the higher activity concentrations of natural radionuclides in these provinces would be partly associated with granitic rocks exposed in the regions. Although the hazard index of activities in beach she-oak bark have not been reported, this study served as the background radioactivity levels which is useful in terms of monitoring the region for human health.

KEYWORDS: radioactive contamination, beach she-oak bark, Naturally Occurring Radioactive Materials, gamma spectroscopy, Thailand's coast

INTRODUCTION

Natural and artificial gamma-emitting radionuclides contribute to radioactive contamination in the environment, have led to human health effects with sufficient exposure. The uranium-238 (^{238}U) series, thorium-232 (^{232}Th) series, and potassium-40 (^{40}K) are the main Naturally Occurring Radioactive Materials (NORM), existing in the earth's crust, building materials, rocks, soil, sand, water, plants, and even in the human body. Radium-226 (^{226}Ra), a decay product in the uranium-238 (^{238}U) series, is one of the most radiologically significant nuclides because of its relatively long half-life (1,600 years), high radiotoxicity and mobility in the environment. It can leach from rocks and soils into groundwater and bioaccumulate in living organisms, particularly in bones due to its chemical similarity to calcium. Therefore, monitoring ^{226}Ra concentrations, along with other natural radionuclides, is essential for assessing environmental radioactivity and potential human health risks [1, 2]. Apart from the majority of the population's exposure to external radiation associated with natural sources [3], there are artificial radionuclides, such as ^{137}Cs that resulted from human activities like nuclear accidents and open-air nuclear weapons testing. After the nuclear accidents from Chernobyl and Fukushima, number of studies have been conducted world-wide to investigate the deposition of ^{137}Cs in soil, sediments, water as well as in plants [4–7]. Due to the earth surface process, geographic and geological influence on non-uniform distribution of radionuclides, activity determination in various species and parts of plants have been increasingly adopted to monitor environment. For example, some studies used lichens, mosses, leaves, stems and barks of various tree species as biomonitor [3, 8–13], especially in Scots pine [14–19]. In the past decade, tree barks have been used to measure radionuclides, organic compound concentrations, and element concentrations in the atmosphere [3, 20, 21]. In comparison with the other parts of the tree, using tree barks as biomonitor of radionuclide contamination has some advantages in terms of sample collection and amounts of radionuclide accumulation from the atmosphere [3]. Tree bark accumulates radionuclides by absorbing them from the atmosphere rather than absorbing them through the roots or by foliar uptake after they have been translocated into the stem from

the leaves. Due to limited diffusion, radionuclides accumulate on the outer bark's surface layers of tree barks have been used as a potential indicator of air pollution since they retain pollutants directly from the air or from the rainwater running down the stems. In addition, the retention of particulate matter in the bark occurs on a humid, rough or electrically charged surface [20].

In coastal area, such as southern peninsular of Thailand, beach she-oak (*Casuarina equisetifolia*) is planted along the coast to block wind and stop erosion caused by seawater. People used beach she-oak in wood processing for making house poles and furniture. Some studies showed that beach she-oak bark is used to make the herb mixture because it has anti-aging properties and it has potential to be a folk medicine for inhibiting diabetes [12]. Assessment of radionuclides in plants along the coastal areas are very important to address the concern about human risk to exposure. Therefore, this study aims to evaluate the activity concentration of radioactive substances in beach she-oak bark as a biomonitor for radioactive contamination. In this work, beach she-oak bark samples collected from 19 provinces along the Thai coast were studied. The radioactivity of ^{137}Cs, ^{226}Ra, and ^{232}Th were determined using a high-purity Germanium (HPGe) detector and gamma spectrometry analysis system. Although there are some previously published data that is related to the radionuclide levels of tree barks [3, 9] the global average concentration level and hazard index of activities in the bark have not been reported. Hence, the present study is the first use of the beach she-oak bark as a bioindicator of radionuclide levels in Thailand.

METHODOLOGY

A total of 28 locations of beach she-oak bark samples were collected from 19 provinces along the coast of Thailand during March 1–10, 2021 as shown in Fig. S1. The representative number of samples were divided into 3 areas, consisting of 9 locations along the coast in the Andaman Sea regions, 8 locations along the coast in the upper Gulf of Thailand and 11 locations along the coast in the lower Gulf of Thailand, respectively. In the representative of each location, bark samples were taken from roughly 3–5 trees of almost the same age and size within an area of 150 square meters. In each location, 500 g of bark samples were collected at the trees' diameter at breast height (DBH) of 1.3 meters above ground as shown in Fig. S2.

Beach she-oak bark samples were prepared based on standard procedures of tree bark samples preparation for atmospheric pollution monitoring [23]. The bark samples were dried in the electric oven at 115 °C for 24 h to remove the moisture. Then, the samples were grinded by the multifunction disintegrator WF-02 and sieved through 2-mm mesh to remove pebbles and other macro-impurities. Each sample was filled up to a maximum height of 5 cm (approximate weight of 90–135 g) in a plastic container with the same dimensions as the calibration standard (7 cm diameter, 6.5 cm height) [18, 22]. All samples were stored in the sealed and labelled plastic container for 30 days in order to reach secular equilibrium of the radionuclides before the activity concentration measurement (Fig. S3). Standard sources, europium ^{152}Eu (Gammadata Instrument AB, Uppsala, Sweden), were used for energy calibration of the measuring system. The well-known reference materials, IAEA/-156 (Radionuclides in clover) obtained from the IAEA (International Atomic Energy Agency, Vienna. Austria) were used to calculate the efficiency of the HPGe detector for analyzing the activity concentration of ^{137}Cs, ^{226}Ra, and ^{232}Th in bark samples. Genies 2000 software (Canbere, USA) was used for comprehensive gamma spectra analysis. The activity of ^{137}Cs was determined based on their 662 keV gamma spectrometry lines, whereas ^{226}Ra and ^{232}Th were obtained from the decay products of ^{214}Bi (609 keV) and ^{228}Ac (911 keV), respectively. Measuring time for each sample is 10,800 s, and the background spectrum was recorded immediately after the sample counting. Activity concentration A in the sample was calculated using equation (1).

$$A = \frac{cps}{Eff \times Y \times W} \tag{1}$$

where A is activity concentrations of the measured sample (Bq/kg), cps is net count rate, Eff is radiation probe efficiency, Y is percentage of gamma radiation emitted by radiation source (%), and W is weight of the measured sample (kg).

The minimum detectable activity (MDA) is measured as the lowest activity level which can be detected by the measuring system using the Currie equation [23] (equation (2)). If the activity in a sample is below MDA, the system cannot detect it during the measurement.

$$\text{MDA} = \frac{2.71 + \left(4.65\sqrt{R_{b,i}}\right)}{Eff \times Y \times t \times W} \tag{2}$$

where $R_{b,i}$ is the standard deviation of the counts in the peak area in the background spectrum, t is counting time (s).

RESULTS AND DISCUSSION

Activity concentrations of radionuclides

Fig. 1 depicts an example of a typical gamma-ray spectrum obtained from the HPGe detector for bark sample in Phuket (Mueang Phuket). Qualitative examination of the spectra revealed the isotopes of ^{212}Pb, ^{214}Pb, ^{214}Bi, ^{228}Ac and ^{137}Cs. Among them, we emphasized on the activity concentration of the three radionuclides as presented in Table 1. It is interesting to note that the concentration value of artificial radionuclide (^{137}Cs) in all bark samples falls below the instrument's detection

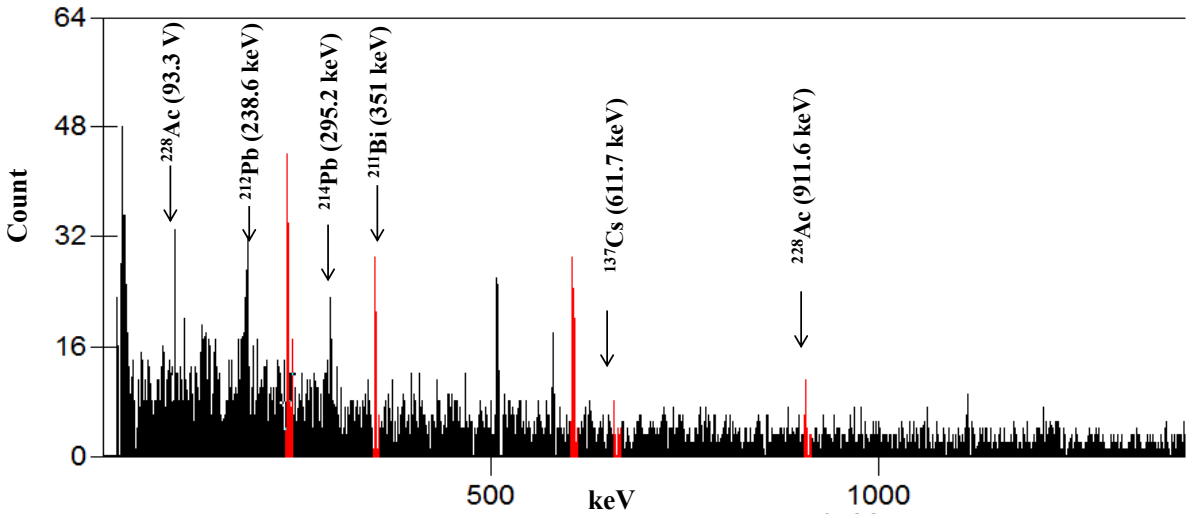

Fig. 1 Gamma-ray spectrum for sample No. 6 in Phuket (Mueang Phuket), acquired using an HPGe detector.

threshold. This indicates that there is no contamination of the radionuclides caused by nuclear accidents, outdoor nuclear weapons testing and human activities along the coastal areas of Thailand. In this study, the measurement results showed that ^{137}Cs was below the detection limit in all analyzed samples, and MDA was approximately 3.2 to 3.8 Bq/kg gamma peak). This suggests that if ^{137}Cs was present in the samples, its activity was likely below this threshold, rather than being entirely absent. Reporting the MDA helps clarify that "not detected" does not mean the radionuclide does not exist, but rather that its activity was too low to be reliably measured under the experimental conditions.

Therefore, the significantly higher levels of radionuclides have been reported in tree bark samples collected from granite mountainous regions, such as parts of Turkey and Romania. These elevated values are primarily associated with the presence of uranium-rich bedrock and granitic formations, which naturally emit higher background radiation. Furthermore, these regions were heavily affected by the Chernobyl nuclear accident in 1986, which caused widespread fallout of ^{137}Cs across Eastern Europe. As a result, forest ecosystems, especially those dominated by tree species like oak (which exhibit higher radionuclide uptake than conifers such as pine), have retained notable levels of contamination over time [3, 28]. The Chernobyl Exclusion Zone remains a well-documented example of long-term environmental contamination. Extremely high levels of ^{137}Cs in tree bark, even decades after the incident, illustrate the persistent nature of radionuclide accumulation in forest ecosystems. This region serves as a reference site for the study of chronic radiation exposure and long-term ecological impacts [28].

From Table 2, the results of this study indicate that the levels of artificial and natural radionuclides in coastal areas of Thailand are very low. In particular, ^{137}Cs was found to be below detection limits (BDL) in all bark samples, suggesting minimal influence from both global nuclear fallout and local geological sources. This observation is consistent with the geologic nature of the region, where sandy coastal soils typically contain very low concentrations of radioactive minerals and have low radionuclide retention capacity due to limited organic content and high permeability [30].

For natural radionuclides, the activity concentrations of ^{226}Ra ranged from 1.3 ± 0.3 to 8.5 ± 0.8 Bq/kg with the mean value of 3.8 ± 0.5 Bq/kg, whereas the activity concentrations of ^{232}Th ranged from 2.6 ± 0.8 to 15.1 ± 1.9 Bq/kg with the mean value of 7.8 ± 1.4 Bq/kg. To examine the effects of coastal morphology, the average activity concentrations of natural radionuclides in the Andaman Sea, the Upper Gulf and the Lower Gulf of Thailand were compared.

The average activity concentration of ^{226}Ra measured in the Andaman Sea, the Upper Gulf and the Lower Gulf of Thailand is found to be 6.2 ± 0.6 Bq/kg, 2.2 ± 0.4 Bq/kg, and 2.9 ± 0.5 Bq/kg, respectively. In addition, the average activity concentration of ^{232}Th measured in the Andaman Sea, the Upper Gulf and the Lower Gulf of Thailand is found to be 9.5 ± 1.5 Bq/kg, 6.51 ± 1.3 Bq/kg, and 7.4 ± 1.4 Bq/kg, respectively. Variations of concentration levels between the Gulf of Thailand and the Andaman Sea could be subjected to the distinct sedimentary dynamics influenced by riverine input, ocean currents, or coastal erosion processes.

In Belgium, studies conducted in agricultural lowland areas have reported moderate levels of ^{226}Ra, which are generally attributed to the natural composition of soils and underlying rock strata. The absence

Table 1 Concentrations of radionuclide activity (Bq/kg) in beach she-oak bark samples collected in the Andaman Sea, Upper Gulf of Thailand, and Lower Gulf of Thailand.

Site No.	Site (Amphoe)	GPS coordinates (°)			Activity concentrations (Bq/kg)					
		N	E	DBH (cm)	^{137}Cs	MDA	^{226}Ra	MDA	^{232}Th	MDA
Andaman Sea										
1	Satun (Mueang Satun)	6.53941	100.06475	19	BDL	3.2	5.7 ± 0.6	3.6	6.9 ± 1.4	5.9
2	Satun (La-ngu)	6.85746	99.71984	20	BDL	3.3	4.6 ± 0.6	3.7	10.7 ± 1.4	4.1
3	Trang (Sikao)	7.49442	99.32721	30	BDL	3.3	6.8 ± 0.6	3.1	9.4 ± 1.4	4.8
4	Krabi (Nuea Khlong)	7.98866	98.97458	12	BDL	3.4	7.6 ± 0.7	3.7	10.2 ± 1.6	5.5
5	Krabi (Laem Sak)	8.27321	98.64761	20	BDL	3.3	7.4 ± 0.7	3.9	11.9 ± 1.7	5.5
6	Phuket (Mueang Phuket)	7.77261	98.32273	20	BDL	3.3	8.5 ± 0.8	4.1	9.3 ± 1.6	6.1
7	Phangnga (Takua Pa)	8.68704	98.24057	15	BDL	3.3	8.4 ± 0.8	3.9	15.1 ± 1.9	4.6
8	Phangnga (Khura Buri)	9.30124	98.37989	20	BDL	3.5	3.0 ± 0.4	3.2	4.1 ± 1.2	5.6
9	Ranong (Kapoe)	9.61686	98.46514	17	BDL	3.3	4.2 ± 0.6	3.9	7.8 ± 1.2	2.7
	Mean						6.2 ± 0.6		9.5 ± 1.5	
	Range						3.0 ± 0.4 – 8.5 ± 0.8		4.1 ± 1.2 – 15.1 ± 1.9	
Upper Gulf of Thailand										
12	Prachuap Khiri Khan (Bang Saphan)	11.20400	99.53312	17	BDL	3.6	1.7 ± 0.3	3.3	5.7 ± 1.1	4.2
13	Prachuap Khiri Khan (Sam Roi Yot)	12.22452	100.00191	15	BDL	3.6	2.4 ± 0.6	4.2	4.3 ± 1.0	3.9
14	Phetchaburi (Cha am)	12.79160	99.98280	19	BDL	3.5	2.8 ± 0.5	3.6	6.9 ± 1.6	6.4
15	Samut Songkhram (Mueang Samut Songkhram)	13.36210	100.02299	13	BDL	3.2	1.9 ± 0.4	3.5	5.9 ± 1.4	6.1
16	Chon Buri (Amphoe Sattahip)	12.84951	100.90128	39	BDL	3.5	2.3 ± 0.4	3.1	7.2 ± 1.2	4.4
17	Rayong (Mueang Rayong)	12.63405	101.33768	25	BDL	3.5	1.9 ± 0.4	3.8	13.0 ± 1.9	6.2
18	Chanthaburi (Mueang Chanthaburi)	12.60512	101.87529	18	BDL	3.4	3.0 ± 0.6	4.0	2.6 ± 0.8	3.9
19	Trat (Laem Ngop)	12.1767	102.38956	20	BDL	3.2	1.3 ± 0.3	3.4	6.5 ± 1.5	6.4
	Mean						2.2 ± 0.4		6.51 ± 1.3	
	Range						1.3 ± 0.3 – 3.0 ± 0.6		2.6 ± 0.8 – 13.0 ± 1.9	
Lower Gulf of Thailand										
10	Chumphon (Lamae)	9.76345	99.14392	15	BDL	3.3	2.4 ± 0.5	3.9	8.6 ± 1.6	3.3
11	Chumphon (Pathio)	10.75060	99.39992	19	BDL	3.4	1.8 ± 0.4	3.8	5.4 ± 1.1	3.4
20	Surat Thani (Don Sak)	9.37601	99.27280	27	BDL	3.5	2.6 ± 0.4	3.4	7.1 ± 1.1	3.5
21	Surat Thani (Chaiya)	9.31932	99.70895	18	BDL	3.7	1.8 ± 0.4	3.6	7.1 ± 1.5	3.7
22	Nakhon Si Thammarat (Sichon)	9.04655	99.91092	16	BDL	3.5	5.0 ± 0.7	4.3	2.9 ± 1.0	3.5
23	Nakhon Si Thammarat (Pak Phanang)	8.32488	100.25653	12	BDL	3.8	4.3 ± 0.7	4.5	8.2 ± 1.3	3.8
24	Songkhla (Sathing Phra)	7.43998	100.45671	20	BDL	3.6	2.5 ± 0.5	4.0	8.0 ± 1.6	3.6
25	Songkhla 2 (Mueang Songkhla)	7.16559	100.63217	16	BDL	3.6	4.5 ± 0.6	4.1	11.8 ± 1.6	3.6
26	Pattani (Nong Chik)	6.85947	101.13955	22	BDL	3.6	2.9 ± 0.5	3.7	8.2 ± 1.7	3.6
27	Pattani (Yaring)	6.89861	101.37291	31	BDL	3.4	1.8 ± 0.5	3.9	6.9 ± 1.4	3.4
28	Narathiwat (Bang Nak)	6.44867	101.82127	24	BDL	3.4	2.5 ± 0.5	3.7	7.7 ± 1.3	3.4
	Mean						2.9 ± 0.5		7.4 ± 1.4	
	Range						1.8 ± 0.4 – 5.0 ± 0.7		2.9 ± 1.0 – 11.8 ± 1.7	

BDL: below detection limit.

or below-detection-level values of ^{232}Th suggest that there are no significant sources of anthropogenic or high natural radioactivity in those areas [27].

Although there are no reports on the global mean specific activities of ^{226}Ra and ^{232}Th in the she-oak bark, comparison with other studies [29, 30] on pine and spruce bark is important in terms of accumulation assessment (Table 2). The data on activity concentrations of radionuclides in different tree bark species show notable variations across species and radionuclides. For example, the study of Belivermiş et al [3] showed different levels of ^{137}Cs, ^{226}Ra, and ^{232}Th in

Table 2 Comparison of ^{137}Cs, ^{226}Ra and ^{232}Th activity concentrations obtained from this study with those from other countries.

Location	Geological Characteristics	Tree bark species	Activity concentrations (Bq/kg)			Reference
			^{137}Cs	^{226}Ra	^{232}Th	
Thailand	Coastal plain, sandy soil, no known radionuclide sources	Beach She-Oak bark	BDL	3.8 ± 1.5	7.8 ± 1.4	This work
Thrace, Turkey	Mountainous, granite-rich area, near Black Sea	Pine bark	4.4 ± 4.8	0.9 ± 0.4	0.8 ± 0.2	Belivermiş et al (2010) [3]
		Oak bark	15.4 ± 22.9	4.0 ± 3.6	8.6 ± 8.3	
Belgium	Lowlands, clay soil, intensive agriculture	Pine bark	—	7 ± 2	BDL	Nathalie et al (2021) [27]
Romania	Forested Carpathian Mountains, uranium-rich bedrock	Oak bark	14	—	—	Constantin et al (2016) [28]
		Spruce bark	45	—	—	
Chernobyl	Highly contaminated zone, pine forests	Scots pine bark	31 ± 17	—	—	Yves et al (2009) [29]

BDL: below detection limit. —: Data not provided.

pine and oak bark measured in the same study area. However, comparison of ^{226}Ra and ^{232}Th concentration of beach she-oak (this study) and oak bark from other study [24] showed comparable activity concentrations. This indicates that the variability in concentrations could be influenced by environmental factors, species-specific uptake, and geographical location.

Spatial variation of the activity concentrations of radionuclides

Since radioactive materials deposited in the environment can migrate to non-contaminated areas by several factors, such as rainfall, wind dispersal and erosion [25], characterization of environmental contaminants in terms of spatial distribution of concentration is essential in environmental monitoring and protection. To represent the spatial distribution of radionuclides in the study area, the concentration distribution maps of ^{226}Ra and ^{232}Th radioactivity are displayed in Fig. S1. It is clearly seen that there are significant differences in radionuclide activity values distributed in the higher latitude ($> 9°$ N) in the upper Gulf of Thailand and in the lower latitude ($< 9°$ N) in the lower Gulf of Thailand and Andaman Sea regions. As mentioned earlier, tree bark retains pollutants directly from the air or from the rainwater running down the stems, in this context, this observation possibly reflects the seasonal and climate related factors, where the upper and lower Gulf of Thailand received difference amount of rainfall. The results are consistent with a study on pine bark of Olivier et al [24], which found that areas with high rainfall had higher radioactivity accumulation than those areas with low rainfall. Moreover, the slight variation observed in distribution of ^{238}U and ^{232}Th in the lower Gulf of Thailand and Andaman Sea regions is likely due to the different of weather and monsoon, which would lead to the accumulation of these nuclides.

In addition, the sampling was conducted in March 2021, which corresponds to the transition period between the end of the cool season and the beginning of the hot season in Thailand. During this time, rainfall is relatively low, sea conditions are calm, and the southwestern monsoon has not yet begun. These environmental conditions limit the runoff of radionuclides from terrestrial sources into the marine environment via rainfall or river discharge. Such conditions may promote the accumulation of radionuclides in coastal areas, particularly in zones with low water exchange. Elevated concentrations of ^{226}Ra and ^{232}Th (as indicated by red and orange markers in Fig. 2) were observed along the southern and lower central coastal regions. This suggests that the reduced water movement during the dry season may allow radionuclides to remain in marine sediments and seawater for longer periods without being dispersed. Conversely, areas with lower radionuclide concentrations (indicated by blue and green markers) may be influenced by freshwater inflows or coastal currents that dilute and transport radionuclides away from the sampling sites. However, since sampling was conducted only during a single dry-season period, the results may not fully reflect the seasonal variability of radionuclide concentrations. Further studies during the rainy or monsoon seasons, when runoff and sediment transport are more dynamic, would provide a more comprehensive understanding of radionuclide behavior and distribution in coastal environments.

It is interesting to note that the highest ^{226}Ra and ^{232}Th concentration values were found in the samples from Phuket and Phang Nga Province, respectively. We suspect that the high concentration of natural radionuclides in these provinces is due to the geological influence, where granitic outcrops are widespread in the areas. It is well-known that regions with granitic rock contain high concentrations of radionuclide, and

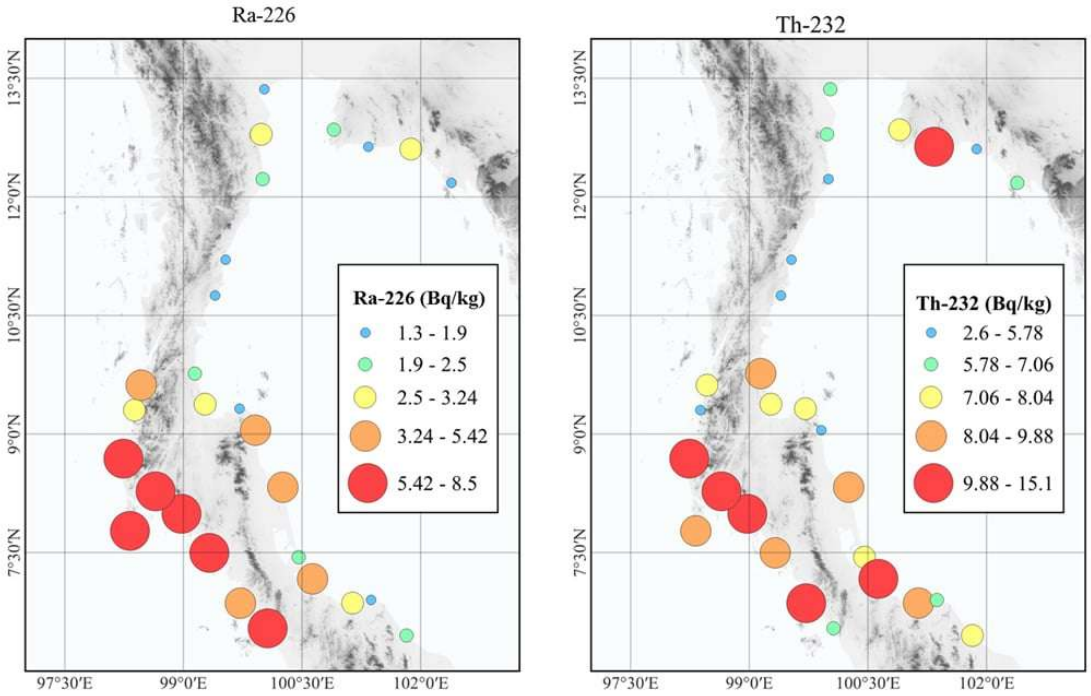

Fig. 2 Map of ^{226}Ra and ^{232}Th concentrations in bark samples from Thailand's coast.

Table 3 Statistic values of the frequency distribution of the activity concentrations of ^{226}Ra and ^{232}Th in beach she-oak bark from 28 sites in Thailand's coastal regions.

Statistic value	^{226}Ra	^{232}Th
Minimum	1.3 ± 0.3	2.6 ± 0.8
Maximum	8.5 ± 0.8	15.1 ± 1.9
Mean	3.8 ± 0.5	7.8 ± 1.4
Median	2.9 ± 0.5	7.4 ± 1.4
Standard Deviation	2.2 ± 0.1	2.9 ± 0.3
Mode	1.8 ± 0.6	6.9 ± 1.6
Skewness	1.018	0.479
Kurtosis	−0.190	0.418

they can migrate to the environment by weathering and erosion process on earth surface [25].

Statistical analysis on the activity concentrations of ^{226}Ra and ^{232}Th radionuclides

To describe the precision, variability and random error of the data and better understand the main factors responsible for the distribution and sampling parameters, statistical analysis was performed in the activity concentration data. This analysis included the frequency distribution along with the mean, median, standard deviation, kurtosis and variant skewness as the results. As illustrated in Fig. 3 and Table 3, the ^{226}Ra and ^{232}Th radionuclides behaved differently in terms of data distribution characteristics. The histogram of ^{232}Th agrees well with the expected calculated normal distribution, whereas the histogram of ^{226}Ra was found to have asymmetrical distribution. The greater skewness value and negative kurtosis value are associated with the activities of ^{226}Ra supporting asymmetric nature and relatively flat distribution. Evaluation of the standard deviation provides insight into the precision or confidence interval around the mean. The higher fractional standard deviation (the ratio of standard deviation and mean) of ^{226}Ra than those of ^{232}Th indicating the higher complexity and variability in measurement of radioactivity.

To gain confidence in the sampling method, correlation between percentage radionuclide content and DBH were analyzed (Fig. 4). Correlation coefficients of the concentration of ^{226}Ra and DBH is −0.23, whereas it is 0.21 for the concentration of ^{232}Th and DBH. The observed weak correlation coefficients indicate that the bark characteristics (the bark's porosity, thickness, and the existence of fissures or cracks) exhibit a little impact on the radionuclide contents or no statistically significant. This implies that there are other factors, such as atmospheric and geological processes affecting radionuclide content in the bark samples.

CONCLUSION

Monitoring of environmental contamination based on the activities of ^{137}Cs, ^{226}Ra, and ^{232}Th in beach she-oak (*C. equisetifolia*) bark samples collected from 19

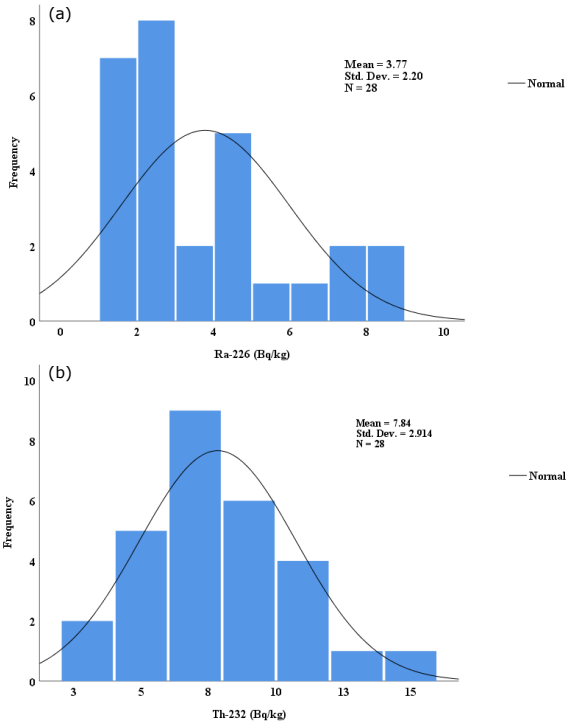

Fig. 3 Frequency data from 28 beach she-oak bark sites in Thailand's coastal regions exhibit a normal distribution (b) and a right-skewed distribution (a).

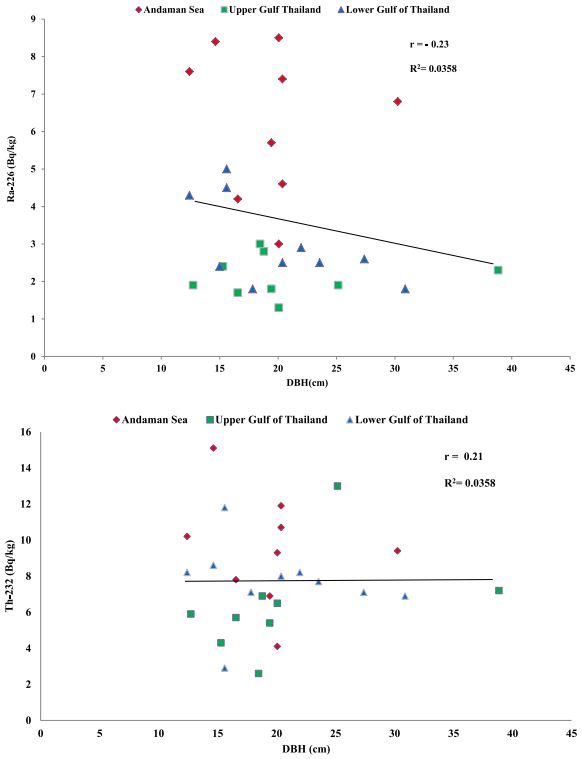

Fig. 4 Relationships between the activity concentrations of ^{226}Ra and ^{232}Th and the diameter at breast height (DBH) in beach she-oak bark samples.

provinces along the Thai coast revealed no evidence of ^{137}Cs contamination, suggesting that the area has not been affected by nuclear power plant accidents or nuclear weapons testing. Although global reference data for radionuclide activity in tree bark are unavailable, this study provides essential baseline information for biomonitoring of ^{226}Ra and ^{232}Th in coastal environments. Noticeable spatial variations in the activities of these radionuclides were observed, likely influenced by geographic, geological, and meteorological factors. The findings emphasize the importance of further experimental investigations of radionuclides in soil and other tree components to better understand potential radioactive contamination and to support effective environmental monitoring and radiation protection along the Thai coastline.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at https://dx.doi.org/10.2306/scienceasia1513-1874.2025.s022.

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Appendix A. Supplementary data

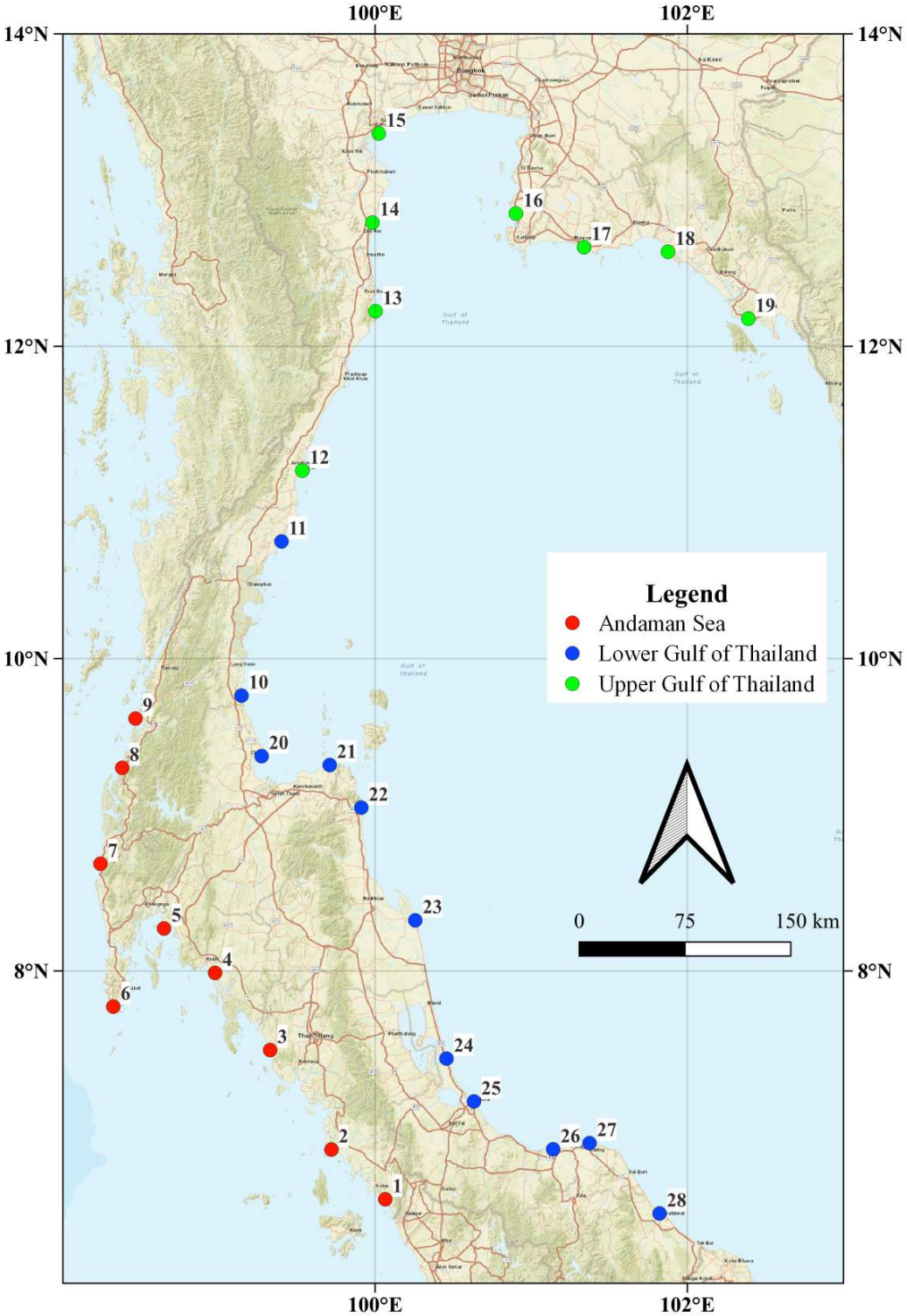

Fig. S1 The locations of the study sites for background radionuclides in beach she-oak bark samples in Thailand's coastal regions.

Fig. S2 A sample of bark from a beach she-oak tree (a). A sample of bark picked by hand at chest height from a beach she-oak tree (b).

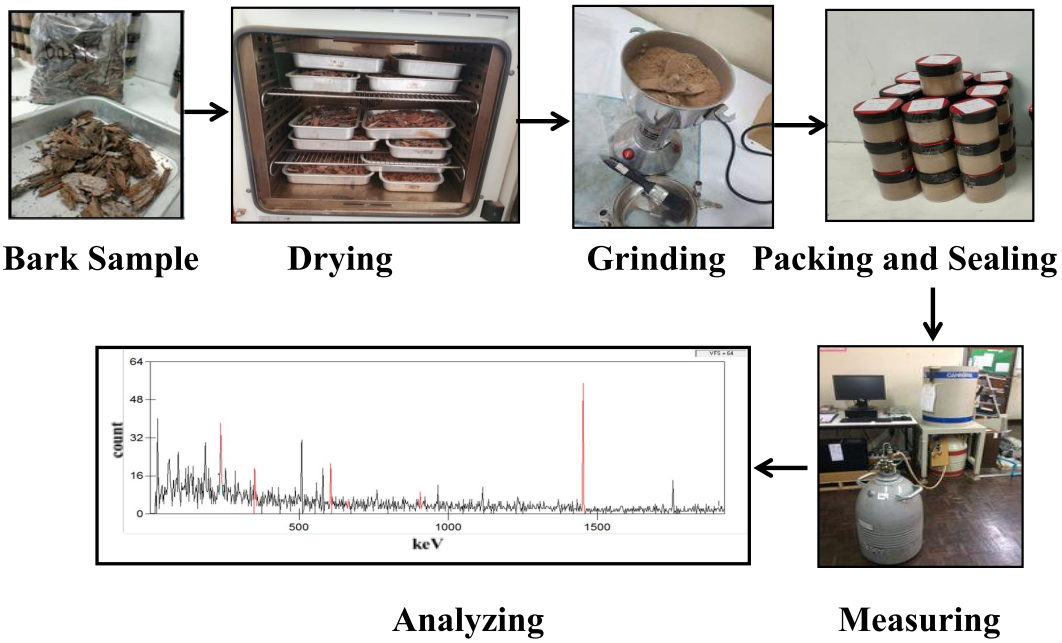

Fig. S3 Sample preparation procedures, measurement procedures and data analysis systems.