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Research article

Concentration of Natural Radionuclides in Soil and Assessment of External Exposure to The Public in Bangka - Belitung Islands, Indonesia

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Abstract

Natural radionuclides in soil such as ^{226}Ra, ^{232}Th and ^{40}K are a significant component of the background exposure sources of the population. Estimation of the external exposure due to gamma-ray radiation of natural radionuclides is important because this may contribute significantly to the total annual individual dose. Bangka Belitung is known as the producer of tin and geologically, contains several times the concentration of natural radionuclides in comparison to other common areas. The aim of this study is to determine the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected from Bangka-Belitung province to assess their contribution to the external dose exposure. Analysis of ^{226}Ra, ^{232}Th and ^{40}K has been carried out in soil samples using γ-ray spectrometry. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K varied from 4.8 – 544 $Bqkg^{-1}$, 7.3 - 2170 $Bqkg^{-1}$, 5.3 – 368 $Bqkg^{-1}$ with a mean value of 72.3, 203 and 70.0 $Bqkg^{-1}$, respectively. The absorbed dose rates due to the presence of ^{226}Ra, ^{232}Th, and ^{40}K, in soil samples in the studied area vary between the range from 7.40 to 1569 $nGyh^{-1}$ with a mean value of 159 $nGyh^{-1}$. The corresponding outdoor annual effective doses ranged between 0.05 – 11.5 mSv y^{-1} with a mean

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value of 1.17 $mSvy^{-1}$. The dose rate in the almost whole area of Bangka Belitung province was higher than the background level. **Copyright © IJSEE, all rights reserved.**

Keywords: Natural radionuclide, Radiation exposure, Gamma ray radiation, Absorbed dose rate, Annual effective dose

Introduction

The major sources of radiological exposure are natural radionuclides namely ^{238}U and ^{232}Th series and ^{40}K, which occur in the earth's crust since its origin. The external exposure of most of these radionuclides to the human body is caused by their gamma radiation [1,2]. Since natural radionuclides is the largest contributor of external dose to the human body, assessment of gamma radiation dose from natural radionuclides sources is of particular importance. The knowledge of the natural radionuclides concentration level in the environment is essential in the assessment of the dose accruing and the health risk to a population.

In most places on the earth, the natural radionuclides varies only within narrow margins, but in some places there are wide deviations from normal levels because of the abundance of minerals with high radioactivity such as monazites, zircons and granite [2,3]. The specific levels are related to the types of rock from which the soils originate. Higher radioactivity in soil samples may be linked to the contribution of the parent materials that constitute the soil type. The soil derived from granite will have a higher radioactivity than the soil from the other rock types [4,5].

Bangka Belitung islands is known as tin producer places which form a part of South East Asia Tin Belt, the richest tin belt in the world which is ranged from South China – Thailand – Myanmar – Malaysia to Indonesia [6]. Bangka Belitung is the producer of tin, which has a long history of more than 200 hundred years. Indonesia's average tin production reach around 70,000 metric tones (tin consentrate) per year, most of it from the Bangka – Belitung islands [7]. Tin mining and processing of by-product-heavy minerals from tin mining such as heavy mineral sand, monazite, ilmenite, zircon or xenotime contain natural radioactive elements which co-exist with the tin ore or cassiterite in the ground has contributed a number of natural radionuclides to the environment [8,9]. Consequently, the activity of tin dressing and refining during the past years which spread over the Bangka - Belitung areas may cause the enhancement of the environmental dose rate due to natural radionuclides.

Bangka-Belitung is one of Indonesia provinces, includes two large islands, Bangka and Belitung, and several smaller ones, which lie east of Sumatra, northeast of South Sumatra province. Bangka Belitung Islands province is the 31st Province in Indonesia, one of the newest provinces [10]. Bangka - Belitung Islands are located at 104° 50' - 109° 30' E and 0° 50' - 4° 10' S. The total area of Bangka-Belitung Islands is about 81,725.14 km^2, consisting of land area about 16,424.14 km^2 or 20.1 percent of the total area and sea area about 65,301 km2 or 79.9 percent of the total area. The hill or mountain lies at the center of Bangka and Belitung Islands. The highest level of topography is 675 m at the mountain in the north part of Bangka Island. In general, the slope at the center of Bangka Island ranged from 5% to 40%, while near the coastline, the slope is very gentle [11].

The objective of this work was to determine the radioactivity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from Bangka – Belitung islands and calculate the air absorbed dose rates due to their gamma rays and evaluate the annual effective dose to the population. The obtained results will serve as base line data for radioactivity level in this environment as the basis for the assessment of the degree of radioactive contamination or pollution in the environment of Bangka - Belitung Islands in the future.

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Theory

Human beings are exposed outdoors to the natural terrestrial radiation that originates predominantly from the soil. A major contribution to the total dose of external exposure comes from radionuclides in ^{238}U, ^{232}Th series and ^{40}K. ^{226}Ra is a radionuclide in the ^{238}U series and its two main daughters are gamma rays emitter namely ^{214}Pb (295.2 and 351.9 keV) and ^{214}Bi (609.3 keV). The outdoor air-absorbed dose rates due to terrestrial gamma rays at 1 m above the ground level can be calculated from ^{226}Ra, ^{232}Th and ^{40}K concentration values in soil by using the following formula : [3,12,13,14]

$$D(nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (1)$$

where D is the absorbed dose rate in $nGy.h^{-1}$, and A_{Ra}, A_{Th} and A_K are the specific activities in Bg kg^{-1} of ^{226}Ra, ^{232}Th, and ^{40}K respectively. The conversion factors 0.462, 0.604, 0.0417 are the corresponding dose conversion coefficients which transform the specific activities into absorbed dose and expressed in $nGyh^{-1}/Bg.kg^{-1}$. These dose coefficients were originally derived from monte Carlo calculation using mathematical phantoms [1,3].

In order to estimate the annual effective dose rate in air to human body, the two factors of importance are the conversion coefficient from Gy h^{-1} to Svh^{-1} and the occupancy factor. The former gives the equivalent human dose in Sv y^{-1} from the absorbed dose rate in air (Gy h^{-1}) while the latter gives the fraction of the time an individual is exposed to outdoor radiation. UNSCEAR [1,3] has been recommended that the conversion coefficient from the absorbed dose in air to the effective dose (0.7 $SvGy^{-1}$) and an outdoor occupancy factor of 0.2, which suggests that from absorbed dose in air to effective dose received by adults. Under these assumptions, the annual effective dose equivalent is calculated by the following equation:

$$E(mSvy^{-1}) = D(nGyh^{-1})x8760(h)x0.2x0.7(SvGy^{-1})x10^{-6} \quad (2)$$

where E is the annual effective dose rate in air ($mSvy^{-1}$) and D is the value of absorbed dose rate earlier calculated from equation 1. The value of 8760 is the time for one year.

Materials and Method

Sample Collection and Preparation

The sampling points were selected by dividing each of the total area of the Bangka and Belitung islands using a square grid as described in systematic random sampling [15]. Geographical coordinates of sampling points were determined using GPS Map 60CHx manufactured by Garmin. Soil samples were taken at flat, spacious and undisturbed sites. Sampling positions were far from trees, buildings, roads or other constructions to avoid the impact of strange materials. Samples were obtained by clearing the surface vegetation and removing dead organic matter from the surface of the location. A total of at least 2 – 3 kg of soil was collected at 5 to 20 cm depth levels at each spot using shovel and scoop. At a collection point the soil sample was wrapped in black plastic bag and then taken to the laboratory.

In the laboratory, the soil samples were dried in an oven at a temperature of 105^0C to a constant weight to remove any available moisture. After drying, the samples were crushed and sieved with a mesh having holes each of diameter of 2 mm in order to remove organic materials, stones and lumps. Afterwards, the homogenized samples were packed to fill 1 liter marinelli beakers. The marinelli beakers were carefully sealed in order to prevent trapped

radon gas from escape and allowed to stand for at least 4 weeks for secular equilibrium to be established between the long-lived parent nuclides of ^{226}Ra and ^{232}Th, and their short-lived daughters before measurement.

Sample Counting

The measurement of the radionuclides in the prepared samples were carried out by using ORTEC P-type coaxial high purity Germanium (HPGe) detector with a relative efficiency of 60% and a resolution of 1.95 keV (full width at half maximum) for the peak of 1,33 keV. The detector was coupled to a multi channel computer based analyzer. The gamma ray spectrum is recorded using a Personal Computer based 4096 channel analyzer and processed using ORTEC Vission-32 Gamma spectrum analysis computer software. The detector is located inside a cylindrical lead shield of 10.1 cm thickness with internal diameter of 28 cm and height of 40 cm. The lead shield is lined with various layers of tin and copper each of 0.5 and 1.6 mm thick respectively.

The detection efficiency calibration of the system for the determination of radionuclides in the prepared samples was carried out using certified standard source (mixed Gamma) and International Atomic Energy Agency (IAEA) reference materials prepared in geometrical shape and composition to simulate the samples' matrix. The measurements were carried out in the counting room located in the basement of laboratory building. The measurement time for samples and background was 17 hours. The background counts was used to correct the net peak area of gamma rays of measured isotopes. Quality assurance was additionally guaranteed by regular participations in national and international intercompararison exercises.

The gamma energy peaks 352 keV of ^{214}Pb and 609.31 keV of ^{214}Bi were used to determine ^{226}Ra. The gamma energy peaks of 238.6 keV from ^{212}Pb, 911.2 and 969 keV gamma energy peak from ^{228}Ac and 583 keV gamma energy peak from ^{208}Tl were used to determine the ^{232}Th, and that of ^{40}K was determined from the gamma energy peak of 1460.83 keV.

The activity concentrations (A) of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} for the samples were determined using the following expression :

$$A = \frac{N_e}{\varepsilon_f P_\gamma t_C M} \tag{3}$$

where; N_e = net counts of a peak at energy E, ε_f = the counting efficiency of the detector system at energy E, P_γ = the gamma ray emission probability (gamma yield) at energy E, t_c = sample counting time, and M = mass of sample (kg). If there is more than one peak in the energy analysis range for a radionuclide, then an attempt to average the peak activities is made. The results are then the weighted average radionuclide activity.

Gamma dose rate and annual effective dose rate calculation

Based on the radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in soil samples, the gamma absorbed dose rate in air in nGy h^{-1} at one meter above the ground level was calculated from equation 1 and annual effective dose rate was calculated by using equation 2.

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Results and Discussion

Activity concentrations

The results of activity concentration measurements in the soil samples collected from Bangka and Belitung islands are shown in Tabel 1 and 2, respectively. The activity concentrations of ^{226}Ra ranged from 16.8 ± 1.3 to 543.8 ± 36.3 $Bqkg^{-1}$ in soils from Bangka and from 4.8 ± 0.7 to 258.1 ± 15.7 $Bqkg^{-1}$ in soils from Belitung with means of 83.8 $Bqkg^{-1}$ and 60.87 $Bqkg^{-1}$, respectively. The activity concentrations of ^{232}Th ranged from 21.3 ± 1.6 to 2170.3 ± 65.2 $Bqkg^{-1}$ in soils from Bangka and from 7.3 ± 0.3 to 742.1 ± 43.6 $Bqkg^{-1}$ in soils from Belitung with means of 244.3 $Bqkg^{-1}$ and 160.94 $Bqkg^{-1}$, respectively. The activity concentrations of ^{40}K ranged from 14.4 ± 2.4 to 191.3 ± 13.5 $Bqkg^{-1}$ in soils from Bangka and from 5.3 ± 1.9 to 367.9 ± 21.3 $Bqkg^{-1}$ in soils from Belitung with means of 55.10 $Bqkg^{-1}$ and 84.96 $Bqkg^{-1}$, respectively.

Table 1: Activity cocentrations in soil collected from Bangka island

Sample No.	Activity cocentrations (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
1.	39.0 ± 2.6	75.7 ± 2.1	103.8 ± 6.4
2.	26.2 ± 2.0	21.3 ± 1.6	14.4 ± 2.4
3.	16.8 ± 1.3	28.0 ± 0.9	31.9 ± 2.3
4.	116.3 ± 7.2	219.7 ± 5.9	23.2 ± 2.7
5.	136.4 ± 8.5	601.2 ± 33.3	67.6 ± 7.1
6.	29.5 ± 2.1	62.5 ± 1.8	48.0 ± 3.3
7.	143.7 ± 9.0	377.4 ± 10.2	34.3 ± 3.3
8.	80.6 ± 5.1	252.6 ± 6.8	45.7 ± 3.5
9.	76.7 ± 5.1	231.0 ± 6.6	57.4 ± 4.1
10.	63.0 ± 4.1	151.7 ± 4.2	29.4 ± 2.6
11.	23.0 ± 1.6	44.3 ± 1.3	48.8 ± 3.3
12.	543.8 ± 36.3	2170 ± 65.2	169.1 ± 11.6
13.	118.4 ± 7.4	510.8 ± 13.6	46.7 ± 4.0
14.	91.2 ± 5.9	109.0 ± 6.4	17.1 ± 3.4
15.	54.5 ± 3.6	115.0 ± 0.5	34.7 ± 4.0
16.	64.4 ± 4.3	155.0 ± 4.3	30.7 ± 2.7
17.	43.2 ± 3.8	77.8 ± 5.2	191.3 ± 13.5
18.	46.0 ± 3.1	97.4 ± 2.7	54.1 ± 3.7
19.	42.1 ± 2.9	123.6 ± 3.4	85.3 ± 5.5
20.	99.6 ± 6.9	158.9 ± 4.6	71.0 ± 6.2
21.	115.2 ± 7.3	206 .8 ± 11.6	63.1 ± 6.4
22.	25.4 ± 1.9	81.4 ± 2.3	48.2 ± 3.3
23.	29.2 ± 2.0	59.0 ± 1.7	19.1 ± 1.9
24.	22.9 ± 1.7	33.2 ± 1.0	45.7 ± 3.1
25.	61.6 ± 4.1	230.6 ± 13.8	53.4 ± 4.2
26.	139.6 ± 8.5	412.7 ± 10.7	59.6 ± 4.6
27.	66.3 ± 4.3	159.7 ± 4.3	30.9 ± 2.7
28.	32.0 ± 2.2	73.2 ± 2.1	19.0 ± 1.8
Range	16.8 – 544	21.3 – 2170	14.4 – 191
Average	83.8	244	55.1

Table 1 and 2 shows that, in general the average and ranges of activity concentrations of ^{226}Ra and ^{232}Th in soil collected from Bangka island are higher than those from Belitung island. High values of ^{226}Ra and ^{232}Th in soil

samples collected from Bangka may be correlated with different patterns of mineralization in both islands. In Bangka Island, mineralizations are formed around the granite bodies, and tin deposits are found mainly in contact zone. In Belitung Island, mineralizations are formed far from the granite bodies. The altitude of the island above the sea level on the Tertiary and Quaternary period has contributed in the weathering intensity, so that influence the characteristics and existences of the primary mineral deposit [6]. Besides that, the increasing of tin mining activities by private company and individual in Bangka island may also be responsible for the enhanced radioactivity in the area. Generally, tin mining leaves some natural radioactivities which easily transfers from the mining location to its surrounding environment which goes up to the land surface [16,17,18].

Table 2: Activity cocentrations in soil collected from Belitung island

Sample No.	Activity cocentrations (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
1.	109.5 ± 7.5	742 ± 43.6	56.3 ± 7.1
2.	71.8 ± 4.7	90.9 ± 2.6	36.6 ± 2.8
3.	22.1 ± 1.6	43.2 ± 1.3	140.1 ± 8.6
4.	57.6 ± 3.7	94.0 ± 2.6	178.4 ± 10.6
5.	41.5 ± 2.8	76.3 ± 2.2	47.0 ± 3.3
6.	68.3 ± 4.5	212.0 ± 6.0	40.9 ± 3.2
7.	4.8 ± 0.7	8.7 ± 0.8	5.3 ± 1.9
8.	18.8 ± 1.7	45.4 ± 3.2	65.4 ± 4.9
9.	33.1 ± 2.3	73.5 ± 2.1	81.1 ± 5.2
10.	34.6 ± 2.3	67.0 ± 1.9	137.9 ± 8.4
11.	10.7 ± 0.9	18.4 ± 0.6	106.6 ± 6.6
12.	101.5 ± 6.3	328.4 ± 19.1	32.5 ± 3.6
13.	169.3 ± 10.6	555.7 ± 32.9	37.4 ± 3.7
14.	55.6 ± 3.8	185.4 ± 5.2	22.7 ± 2.2
15.	5.8 ± 0.6	7.3 ± 0.3	7.4 ± 0.9
16.	46.8 ± 3.1	99.6 ± 2.8	15.3 ± 1.7
17.	80.1 ± 5.0	196.5 ± 11.5	367.9 ± 21.3
18.	18.3 ± 1.4	41.6 ± 1.2	49.3 ± 3.3
19.	89.5 ± 5.7	188.2 ± 5.1	28.2 ± 2.6
20.	36.6 ± 2.9	100.4 ± 6.4	345.5 ± 21.1
21.	25.9 ± 2.0	35.7 ± 2.3	65.6 ± 4.8
22.	49.3 ± 3.6	102.5 ± 6.4	95.3 ± 7.1
23.	27.9 ± 2.0	46.0 ± 1.3	72.7 ± 4.7
24.	46.2 ± 3.1	119.6 ± 7.2	77.4 ± 5.0
25.	46.0 ± 3.2	115.6 ± 9.0	77.1 ± 4.1
26.	53.4 ± 3.5	78.1 ± 4.8	26.1 ± 2.2
27.	258.1 ± 15.7	653.8 ± 38.0	298.0 ± 17.6
28.	27.9 ± 2.0	46.0 ± 1.3	72.7 ± 4.7
29.	178.2 ± 11.0	376.7 ± 10.2	94.2 ± 6.5
30.	194.8 ± 12.2	492.8 ± 28.7	37.2 ± 5.4
31.	34.2 ± 2.4	95.0 ± 2.5	252.2 ± 14.5
32.	15.9 ± 1.2	17.0 ± 0.6	18.5 ± 1.6
33.	12.5 ± 1.9	20.0 ± 2.0	6.7 ± 5.0
34.	12.8 ± 1.0	11.9 ± 0.4	16.0 ± 1.4
35.	85.1 ± 5.9	308.9 ± 18.2	31.6 ± 4.4
36.	46.8 ± 3.1	99.6 ± 2.8	15.3 ± 1.7
Range	4.8 – 258	7.3 – 742	5.3 – 368
Average	60.87	161	84.96

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The activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples from studied area was compared with those from similar investigation in some other contries as given in Table 3. It can be seen that ^{226}Ra and ^{232}Th values higher than other countries. In contrast values of ^{40}K obtained in this study fall within the lowest side of all reported values from other countries. It may be caused by the possible rise in concentration level due to accumulation of mineral sands from various mining activities in Bangka – Belitung islands.

Table 3: Comparison Activity cocentrations in soil with those in other countries [3,5,19]

Country	Activity cocentrations (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
Norway	50	45	850
Malaysia	67 (38-94)	82 (63-110)	310 (170-430)
Egypt	17 (5-64)	18 (2-96)	320 (29-650)
US	40 (8-160)	35 (4-130)	370 (100-700)
Argentina	-	-	650 (540-750)
Bangladesh	34 (21-43)	-	350 (130-610)
China	32 (2-440)	41 (1-360)	440 (9-1800)
Hong Kong SAR	59 (20-110)	95 (16-200)	530 (80-1100)
India	29 (7-81)	64 (14-160)	400 (38-760)
Japan	33 (6-98)	28 (2-88)	310 (15-990)
Thailand	48 (11-78)	51 (7-120)	230 (7-712)
Korea, Rep. of	-	-	670 (17-1500)
Iran	28 (8-55)	22 (5-42)	640 (250-980)
Denmark	17 (9-29)	19 (8-30)	460 (240-610)
Belgium	26 (5-50)	27 (5-50)	380 (70-900)
Luxembourg	35 (6-52)	50 (7-70)	620 (80-1800)
Switzerland	40 (10-900)	25 (4-70)	370 (40-1000)
Bulgaria	45 (12-210)	30 (7-160)	400 (40-800)
Poland	26 (5-120)	21 (4-77)	410 (110-970)
Romania	32 (8-60)	38 (11-75)	490 (250-1100)
Greece	25 (1-240)	21 (1-190)	360 (12-1570)
Portugal	44 (8-65)	51 (22-100)	840 (220-1230)
Spain	32 (6-250)	33 (2-210)	470 (25-1650)
Germany	(5-200)	(7-134)	(40-1340)
Hungary	33 (14-76)	28 (12-45)	370 (79-570)
Cyprus	17 (0-120)	-	140 (0-670)
Netherlands	23 (6-63)	(8-77)	(120-730)
India (Himachal Pradesh)	57 (42-80)	82 (53-106)	136 (95-160)
World average	35	30	400
Present work	72.3 (4.8-544)	202.6 (7.3-2170)	70.0 (5.3-368)

Note : - data is not available

Absorbed dose rate in air

The terrestrial gamma dose rate in the outdoor air was evaluated from the activity concentrations of the ^{226}Ra, ^{232}Th and ^{40}K measured in soil samples as given in column 2 and 4 of Table 4. The values of absorbed dose rates were calculated based on above equation 1. The values of absorbed dose rates in air due to the presence of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples in the studied area vary between the range from 25.57 to 1569 nGyh^{-1} with a mean value of 189 nGyh^{-1} for Bangka island and 7.40 to 527 nGyh^{-1} with a mean value of 129 nGyh^{-1} for Belitung island.

Table 4: Absorbed dose rate and Annual effective dose rate from the soil at Bangka Island

No.	Bangka Island		Belitung Island	
	Absorbed Dose rate ($nGy.h^{-1}$)	Effective Dose Rate ($mSv.y^{-1}$)	Absorbed Dose rate ($nGy.h^{-1}$)	Effective Dose Rate ($mSv.y^{-1}$)
1.	68.07	0.50	501.17	3.69
2.	25.57	0.19	89.60	0.66
3.	26.00	0.19	42.15	0.31
4.	187.40	1.38	90.83	0.67
5.	428.96	3.16	67.22	0.49
6.	53.38	0.39	161.31	1.19
7.	295.77	2.18	7.69	0.06
8.	191.71	1.41	38.83	0.29
9.	177.35	1.31	63.07	0.46
10.	121.96	0.90	62.21	0.46
11.	39.42	0.29	20.50	0.15
12.	1569.15	11.55	246.60	1.81
13.	365.17	2.69	415.42	3.06
14.	108.68	0.80	138.62	1.02
15.	96.09	0.71	7.40	0.05
16.	124.65	0.92	82.42	0.61
17.	74.93	0.55	171.03	1.26
18.	82.34	0.61	35.64	0.26
19.	97.66	0.72	156.20	1.15
20.	144.95	1.07	91.96	0.68
21.	180.76	1.33	36.26	0.27
22.	62.91	0.46	88.66	0.65
23.	49.92	0.37	43.71	0.32
24.	32.54	0.24	96.81	0.71
25.	169.97	1.25	94.29	0.69
26.	316.25	2.33	72.93	0.54
27.	128.38	0.94	526.56	3.87
28.	59.79	0.44	43.71	0.32
29.	-	-	313.78	2.31
30.	-	-	389.20	2.86
31.	-	-	83.70	0.62
32.	-	-	18.39	0.14
33.	-	-	18.13	0.13
34.	-	-	13.77	0.10
35.	-	-	227.21	1.67
36.	-	-	82.42	0.61
Range	25.57 – 1569	0.19 – 11.55	7.40 – 527	0.05 – 3.87
Average	189	1.39	129	0.94

Note : - data is not available

Annual effective dose equivalent

The results from the calculation of annual effective dose values based on equation 2 are shown in column 3 and 5 of Table 4. It can be seen that the outdoor annual effective doses at locations in Bangka and Belitung islands where the soil samples have been collected vary between the range from 0.19 to 11.55 mSv y^{-1} with an average

value of 1.39 mSv y^{-1} for Bangka island and 0.05 to 3.87 mSv y^{-1} with an average value of 0.94 mSv y^{-1} for Belitung island.

^{232}Th had the highest value of total absorbed dose rate among the three radionuclides detected in the soil samples collected from Bangka-Belitung islands. This indicate that the main contributor to external gamma radiation in Bangka Belitung is ^{232}Th. Based on the activity concentrations in Table 1 and 2, it can be calculated that ^{232}Th contributes highly in the external exposure dose rate than ^{226}Ra and ^{40}K in the both islands. The average percentage contributions to the external dose rate from ^{226}Ra, ^{232}Th and ^{40}K are 21 %, 77 % and 2 % respectively.

The results obtained from the calculation of absorbed dose rate and annual effective dose values for Bangka and Belitung islands are higher than the world average as can be seen in Table 5. The annual effective dose rate for Bangka and Belitung islands are respectively 20 and 13 times higher than the world average value of 0.070 $mSvy^{-1}$ for outdoor terrestrial radiation of regions of normal background radiation [3]. The mean value of outdoor annual effective dose equivalent estimate from this study is 1.17 mSv.

Table 5: Comparison absorbed dose rate and Effective dose rate with world average [5,20,21,22]

Region	Absorbed Dose rate ($nGy.h^{-1}$)	Effective Dose Rate ($mSv.y^{-1}$)
Bangka island	189 (25.57-1569)	1.39 (0.19-11.55)
Belitung island	129 (7.40-527)	0.94 (0.05-3.87)
World average	56	0.070

Conclusion

The activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil of Bangka and Belitung islands have been determined by using gamma-ray spectroscopy. Generally, the average and ranges of activity concentrations of radionuclides in soil collected from Bangka and Belitung islands are higher than the world average, except for ^{40}K. Based on those radionuclides levels in soil, the mean value of the gamma absorbed dose rate in air was calculated to be 159 nGy h^{-1}. Then, the mean value of outdoor annual effective dose equivalent estimate from this study is 1.17 mSv. From this work, it was found that Bangka Belitung islands have the annual outdoor effective dose higher than the world average value of 0.07 $mSvy^{-1}$ for outdoor terrestrial radiation of regions with normal background radiation specified by UNSCEAR. Thus, the exposure level for the members of general public is higher than the recommended value of 1 $mSv.y^{-1}$. Therefore, this is an indication that the mining activities in Bangka Belitung islands appear to have any impact on the radiation burden of the environment.

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