Assessment of Natural Radioactivity Levels in Soil of Bali Island, Indonesia

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Abstract: *Bali is a popular resort and tourist destination in the world because of its culture and beautiful natural view. The purpose of this study is to investigate the natural radioactivity in soil samples collected from various locations in the area of Bali island and assess the radiological hazard due to its natural radionuclides. The soil samples were analyzed for natural radionuclides such as ^{226}Ra, ^{232}Th, and ^{40} by using gamma spectometry analysis. In order to evaluate the radiological hazard of the natural radioactivity, the radium equivalent activity (Raeq), the absorbed dose rate (D), the annual effective dose rate (E), the external hazard index (Hex), and the internal hazard index (Hin) were calculated and compared with the internationally approved values. The natural radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K measured from these samples were found to lie in the range 8.43 – 21.99, 11.37 – 27.84 and 106.04 – 360.53 Bq/kg respectively. The radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K within the areas are lower than the world wide average values. The hazard indices calculated were all less than unity (≤ 1) and within the acceptable limit. The annual effective dose rate in the soil samples collected from the area estimated to be 0.03 mSv which is lower than the worldwide average value of 0.07 $mSvy^{-1}$. The present work provides a background of radioactivity concentrations in the soil of Bali island.*

Keywords: Natural radioactivity, soil, radiological hazards.

Introduction

Studies of the distribution of naturally occurring radioactivity levels in the environment is important for assessing the radiation exposure of the population. Natural radioactivity arises mainly from primordial radionuclides, such as ^{40}K and the nuclides from the ^{232}Th and ^{238}U series and their decay products, which occur at trace levels in all ground formations. Terrestrial gamma rays are essentially due to radionuclides belonging to ^{238}U and ^{232}Th series and singly occurring ^{40}K that are present in the earth'scrust. The activity concentration of natural radionuclide in soil is one of the main determinants of the natural background radiation. Gamma radiation emitted from such naturally occurring radionuclides is present in all soil and represents the main external exposure to the human body. The specific radiation levels are related to the content of the radionuclides in the soil, which in turn depends on some parameters such as the nature of the parent rock during soil genesis, geological and geographical conditions. Chemical and biochemical interactions influence the distribution patterns of uranium, thorium, and their decay products in soil (El-Gamal et al. 2013, Suresh et al.2011). To evaluate the natural radioactivity level in soils, usually determined from the ^{226}Ra, ^{232}Th and ^{40}K contents. Since 98.5% of the radiological effects of the uranium series are produced by radium and its daughter products, the contribution from the ^{238}U and the other ^{226}Ra precursors are normally ignored.

Investigation of soil radioactivity can provide reference data in observing the possible future anthropomorphic impact. This investigations can be useful for both the assessment of public dose rates and the performance of epidemiological studies, as well as to keep reference–data records, in order to ascertain possible changes in the environment radioactivity due to human activities, industries and natural disaster. Naturally occurring radioactivity has led to the performance of extensive surveys in many countries of the world. Several studies were carried out to assess the average outdoor terrestrial gamma dose rate in air at 1 m from the ground (Ravisankar et al. 2012; El Samad et al. 2013, Ademola, et al. 2014, Syarbaini, et al. 2015).

The objectives of the present study are to measure the natural radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K in the surface soil of Bali island. The obtained data in this study are to assess the radium equivalent activity, the air absorbed external gamma radiation exposure, annual effective radiation dose, external radiation hazard index, and internal radiation hazard index and to compare the results with international levels. The data generated in this study provide baseline values of natural radioactivity in Bali soils and may be useful for authorities in the implementation of radiation protection standards for the general population in the Indonesian country as well as to plan and conduct further studies on this issue.

Materials and Methods

Study Area

Bali is an island and one of province in Indonesia. The island of Bali lies 3.2 km east of Java, and is approximately 8 degrees south of the equator. Bali and Java are separated by the Bali Strait. East to west, the island is approximately 153 km wide and spans approximately 112 km

north to south; administratively it covers 5,780 km^2, or 5,577 km^2 without Nusa Penida District, its population density is roughly 750 people/km^2. Bali is dominantly covered by volcanic rocks, overlying the Tertiary carbonate rocks that outcrop in the southern and western part of the island (Purnomo et al., 2015). It is located between 8°3'40" - 8°50'48" South latitudes and 114°25'53" - 115°42'40" East longitude with the area of approximately 5,577 km^2. Its capital of Denpasar is located at the southern part of the island.

Figure 1. The map of Bali island

Sample Preparation and Measurement

All soil samples were collected from each areas by random selection. After collection, each soil sample was wrapped in black plastic bag and labelled according to the name of the location where it is located. The geographical coordinates of the sampling point were recorded by Global Positioning System(GPS).

In the laboratory, the soil samples were dried in an oven at a temperature of 105^{0}C 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.

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. To reduce the external gamma-ray background in the measured spectrum, the detector was 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 energy and 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 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. Since the absolute efficiency were employed in the same Marinelli beaker geometry and the same approximate density as the samples, the difference in the self-attenuation for gamma rays in the sources and samples was assumed to be negligible. Quality assurance was additionally guaranteed by regular participations in national and international inter-compararison 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 :

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

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) .

Results and Discussion

Natural Radionuclides in Soil Samples

Table 1 shows that the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K ranged from 8.43±0.89 to 21.99±1.85 Bq kg^{-1} with an average of 14.63±1.24 Bq kg^{-1}, from 11.73±0.85 to 27.84±1.85 Bq kg^{-1} with an average of 17.99±1.38 Bq kg^{-1}, and from

106.04±6.62 to 360.53±21.74 Bq kg^{-1} with an average of 218.61±13.15 Bq kg^{-1}, respectively. The total activity concentration of the three radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in the studied soil samples ranged from 126.48 to 398.91 Bq kg^{-1} with an average of 251.22 Bq kg^{-1}. The concentration of ^{40}K accounts for approximately 87 % of the total gamma activity of the soil samples, which indicates that the specific activity due to ^{40}K is the largest contributor to the total activity for all soil samples. The mean values of ^{226}Ra, ^{232}Th and ^{40}K concentrations in soil samples collected from different locations in Bali are lower than the worldwide population-weighted average values in soil (32, 45 and 420 Bq kg−1, respectively) (UNSCEAR, 2000).

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 2. It can be seen that ^{226}Ra, ^{232}Th and ^{40}K values obtained in this study lower than all reported values from other countries.

Radium Equivalent Activity

Radium equivalent activity (Ra_{eq}) is used to assess the hazards associated with materials that contain ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, which is, determined by assuming that 370 Bq/kg of ^{226}Ra or 259 Bq/kg of ^{232}Th or 4810 Bq/kg of ^{40}K produce the same gamma dose rate (UNSCEAR, 2000.). The Ra_{eq} of a sample in (Bq/kg) can be calculated using the following formula :

$$Raeq = A_{Ra} + 1.43A_{Th} + 0.077A_{K}$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in $Bqkg^{-1}$, respectively.

As seen from Table 3, the Raeq values for the soil samples of Bali island vary from 33.77 to 73.78 Bq kg^{-1} with an average of 57.18 Bq kg^{-1}. These values are less than the recommended value of 370 Bq kg^{-1} (Al-Sulaiti, H.A. 2011) and as such do not pose a radiological hazard.

Radiological Hazards

Table 1. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples

Sample number	Activity concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
1	20.61 ± 1.62	17.78 ± 1.28	360.53 ± 21.74
2	14.93 ± 1.22	17.08 ± 3.84	206.50 ± 12.41
3	10.33 ± 0.96	16.81 ± 1.17	205.25 ± 12.29
4	14.27 ± 1.13	21.32 ± 1.45	242.90 ± 14.42
5	15.23 ± 1.27	15.57 ± 1.08	266.91 ± 15.94
6	14.58 ± 1.15	14.13 ± 0.98	248.79 ± 14.70
7	17.45 ± 1.39	18.25 ± 1.25	233.04 ± 13.90
8	17.49 ± 1.46	27.84 ± 1.85	200.77 ± 12.13
9	13.94 ± 1.16	14.64 ± 1.03	224.79 ± 13.40
10	13.08 ± 1.19	15.61 ± 1.12	133.73 ± 8.28
11	13.11 ± 1.11	11.37 ± 0.85	257.31 ± 15.41
12	16.08 ± 1.31	12.80 ± 0.98	294.32 ± 17.74
13	13.18 ± 1.24	15.33 ± 1.11	240.81 ± 14.44
14	10.79 ± 1.02	19.61 ± 1.34	305.47 ± 18.05
15	8.43 ± 0.89	12.02 ± 0.87	106.04 ± 6.62
16	16.07 ± 1.29	22.67 ± 1.51	124.45 ± 7.67
17	14.03 ± 1.27	26.70 ± 1.80	190.02 ± 11.44
18	12.26 ± 1.04	20.61 ± 1.41	119.69 ± 7.31
19	14.73 ± 1.17	18.73 ± 1.26	164.68 ± 9.96
20	21.99 ± 1.85	20.89 ± 1.54	246.16 ± 15.17
Range	8.43 – 21.99	11.37 – 27.84	106.04 – 360.53
Average	14.63 ± 1.24	17.99 ± 1.38	218.61 ± 13.15

Table 2. Comparison Activity cocentrations in soil with those in other countries

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

Table 3. The radiological hazard parameters of Soil

Sample number	Radium equivalent activity (Raeq,Bq kg^{-1})	Absorbed dose rate (D, nGy h^{-1})	Annual effective dose rate (E, mSv year^{-1})	External hazard index (H_{ex})	Internal hazard index (H_{in})
1	73.78	35.29	0.04	0.12	0.25
2	55.25	25.82	0.03	0.15	0.19
3	50.17	23.48	0.03	0.14	0.16
4	63.46	29.60	0.04	0.17	0.21
5	58.04	27.57	0.03	0.16	0.20
6	53.94	25.64	0.03	0.15	0.19
7	61.49	28.80	0.04	0.17	0.21
8	72.75	33.26	0.04	0.20	0.24
9	52.18	24.65	0.03	0.14	0.18
10	45.69	21.04	0.03	0.12	0.16
11	49.17	23.65	0.03	0.13	0.17
12	57.04	27.43	0.03	0.15	0.20
13	53.64	25.39	0.03	0.14	0.18
14	62.35	29.57	0.04	0.17	0.20
15	33.77	15.57	0.02	0.09	0.11
16	58.06	26.30	0.03	0.16	0.20
17	66.84	30.53	0.04	0.18	0.22
18	50.95	23.10	0.03	0.14	0.17
19	54.19	24.99	0.03	0.15	0.19
20	70.82	33.04	0.04	0.19	0.25
Range	33.77 – 73.78	15.57-35.29	0.02-0.04	0.09-0.20	0.11-0.25
Average	57.18	26.74	0.03	0.15	0.19

Absorbed Dose Rate

The absorbed dose rates (D) due to terrestrial gamma rays in air at 1m above the ground surface

can be calculated from ^{226}Ra, ^{232}Th and ^{40}K concentration values in soil based on guidelines provided by UNSCEAR 2000 [3]. The contribution of natural radionuclides to the absorbed dose rate in air (D) depends on the natural specific activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K. The greatest part of gamma radiation comes from these radionuclides. Based on the radionuclide radioactivity in Table 1, the exposure dose rate in air at 1 m above the ground can be calculated using the equation :

$$D(nGyh^{-1}) = (0.462\,A_{Ra} + 0.604\,A_{Th} + 0.0417\,A_K) \quad (3)$$

Where D is calculated the absorbed dose rate (nGy/h). A_{Ra}, A_{Th} and A_K are the activity concentrations (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K in soil samples respectively. In the above conversion factors, it is assumed that all the decay products of ^{226}Ra and ^{232}Th are in radioactive equilibrium. The conversion factors 0.462, 0.604, 0.0417 are expressed in nGy.h^{-1}/Bq.kg^{-1}. Table 3 presents the results of the absorbed dose rates calculated. The absorbed dose rates in air are usually related to human absorbed dose in order to assess radiological implications. The absorbed dose rates in air for this result vary from 15.57 to 35.29 nGy h^{-1} with an average value of 26.74 nGy h^{-1},which is lower than the international recommended value of 55 nGy h^{-1} (UNSCEAR, 2000).

Annual Effective Dose Rate

In order to estimate the annual effective dose rate in air, the conversion coefficient from absorbed dose in air to effective dose (0.7 SvGy^{-1}) and outdoor occupancy factor (0.2) proposed by UNSCEAR [3] are used. The annual effective dose is calculated using the following formula:

$$E(mSvy^{-1}) = D(nGyh^{-1}) \times 8{,}760h \times 0.2 \times 0.7SvGy^{-1} \times 10^{-6} \quad (4)$$

The results of the calculation are given in Tables 3. The annual effective dose rate values of Bali island vary from 0.02 to 0.04 mSv year^{-1}, and the average value was found to be 0.03 mSv year^{-1}. The world average annual effective dose equivalent from outdoor terrestrial gamma radiation is 0.07 mSv year^{-1} (UNSCEAR 1988). So, the obtained values are much lower than the average worldwide value.

External Hazard Index

The external hazard index is an evaluation of the hazard of the natural gamma radiation. The main objective of this index is to limit the radiation dose to the admissible permissible dose equivalent limit of 1 mSvy^{-1}. The external hazard index (Hex) can be calculated using the following formula :

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4{,}810} \leq 1 \quad (5)$$

This model takes into consideration that the external hazard which is caused by gamma-rays corresponds to a maximum radium-equivalent activity of 370 Bq/kg for the material. The external hazard index should be below the unity for the radiation hazard to be negligible. The external hazard index for this study ranged from 0.09 to 0.20 with an average value of 0.15,which is lower than unity, so that the radiation radiation hazard below that of significant health risks.

Internal Hazard Index

Beside to external hazard index, the internal hazard index should be less than unity for the radiation hazard to be considered negligible. Inhalation of alpha particles emitted from the short-lived radionuclides radon (^{222}Rn, the daughter product of ^{226}Ra) and thoron (^{220}Rn, the daughter product of ^{232}Th) are also hazardous to the respiratory tract. This hazard can be quantified by the internal hazard index (H_{in}) [3,7], which is given by the equation:

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \leq 1$$

The internal hazard index should also be less than unity to provide safe levels of radon and its short-lived daughters for the respiratory organs of individuals.
As can be seen in Table 3, the internal hazard index for the present work ranged from 0.11 to 0.25 with an average value of 0.19,which is lower than the above international recommended value.

Conclusion

The evaluation of activity concentration of naturally occurring radionuclides in the soil samples collected from Bali island was conducted. The present study focused on the determination of the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples and the resulting radiation dose from these radionuclides. Then, the estimation of the radium equivalent activity, absorbed gamma dose rate, annual effective dose rate, external hazard index, and internal hazard index of the investigated

soil was carried out. In generall, the average and ranges of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples are lower than the worldwide average values. The gamma absorbed dose rate, the radium equivalent (Ra_{eq}), the external and internal hazard indices (H_{ex} and H_{in}) and annual effective dose equivalent which were determined for each of the soil samples indicate that the radiological hazard indices were found to be within the radiological protection recommended limits. Therefore, the area of Bali island can be regarded as having normal levels of natural background radiation. Therefore, the soil from these regions is safe without posing any significant radiological threat to population and their cumulative effects may have negative consequence on the environment. The data presented in this study will serve as a baseline survey for primordial radionuclide concentration in the study area and also gives a baseline for the proper assessment of radiation exposure to area inhabitants.

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