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THE NATURAL RADIONUCLIDE ACTIVITY AND THE RISK OF POTENTIAL RADIATION IN HEALTH EFFECT: A STUDY ON BEACH SAND IN MADURA, BALI, AND LOMBOK

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Abstract

Introduction: Beach sand is one of the widely used aggregates in construction, especially in coastal areas. However, beach sand contains a hidden risk, namely radioactive hazards. This research will analyze the radioactive activity of nuclides ^{226}Ra, ^{232}Th, and ^{40}K on beach sand and calculate the health risk potential in radiation exposure to the household. *Methods:* Beach sands sampling was carried out on Madura Island, Bali, and Lombok in 2016. All samples were oven-sifted and then put into Marinelli to be chopped using high-purity germanium (HPGe) gamma-ray detectors for three days. *Results and Discussion:* The average of ^{226}Ra, ^{232}Th, and ^{40}K radionuclide activity on the beach sand in Madura were respectively 31.46 Bq/kg, 40.12 Bq/kg, and 334.04 Bq/kg; in Bali were 25.10 Bq/kg, 7.71 Bq/kg, and 165.15. Bq/kg; and in Lombok the amount is 25.88 Bq/kg, 8.25 Bq/kg and 171.99 Bq/kg. The calculation of the radium equivalent (Raeq) value on beach sand in Madura, Bali, and Lombok has the highest value of 132.72 Bq/kg, 54.06 Bq/kg, and 55.92 Bq/kg. The gamma index (I) in Madura, Bali, and Lombok was 1.02; 0.39; and 0.40. For the calculation of Hex and Hin in Madura, Bali, and Lombok, the highest were 0.38; 0.15; 0.15; and 0.48; 0.23; 0.24. *Conclusion:* The activity of the three types of natural radionuclides from the three regions is still below the threshold value. Analysis of potential health risks showed in the gamma index value (I) indicator, which exceeds the safe threshold in the Madura beach sand sample.

INTRODUCTION

Geological characteristics show that beach sand origin from sand carried by rivers, wind gusts, or weathering of various types of objects (1). Beach sand is often used as an aggregate of raw material in the construction sectors (2). As the need for beach sand as a raw material in construction increases, the demand is even higher, especially by people who live on the coast. They used beach sand for making mortals, which will produce strong mortals with the proper composition (3). Other studies show that the mix of beach sand with shells increases the strength compressive of the mortals (2). Thus, it is predicted that the demand for beach sand will keep increasing from time to time.

However, exposure to the beach sand frequently can give potential hazards to humans such as radioactive (4), which arise naturally from the sand itself, or pollutants carried by sea waters and deposited on the beach or marine sediments. These radioactive elements will emit ionizing radiation in gamma, alpha, and beta rays with high solubility and mobility, which cause significant health problems (5), especially a threat to the building occupants (6).

In general, radionuclides found in the sand are natural and called Naturally Occurring Radioactive Materials (NORMs). Radionuclides such as uranium and thorium are found on the earth occurred naturally (6). The amount of radionuclide concentration will be greatly influenced by geological conditions, mineral composition, and different pollutant sources in each region (7). Many studies suggested that beach sand consists of various radionuclides elements such as ^{226}Ra (Radium), which is a decay of ^{238}U, ^{232}Th (Thorium), and ^{40}K (Potassium). These three radionuclides are the most abundant and have long half-lives in the sand (8).

The amount of sand used in building construction will determine the level of radiation exposure to the occupants within a certain period (9). According to the previous study, information regarding the potential radioactive hazards in beach sand can be recommended to stakeholders in many countries to adopt regulations not to use it as building materials.

Several studies have been conducted to determine the magnitude concentration of the radionuclides in beach sand, such as in Thailand (10), in the Canary Islands (11), in India (12), and Las Canteras, Spain (13). The total radiation dose has received by humans does not only come from natural radionuclides such as the combination of ^{40}K, ^{232}Th, and ^{226}Ra. However, there is also cosmic radiation, such as photons and muons. There has been a safe recommendation set to threshold limit the dose of radiation exposure to humans. Meanwhile, Brazil, India, and China are considered countries with the highest radiation exposures (14).

Several other studies have also been conducted to examine the activity of natural radionuclides and their potential hazards in building materials such as ceramics (6,15-16), gravel (15), sand (15), cement (15-18), and bricks (15,18). Moreover, these studies also examined both internal and external hazards that these radionuclides can potentially give to the building occupants.

Internal and external radiations refer to ionizing radionuclides expose to the building occupants from inside or outside the body. Internal radiations such as radium and thorium have become health problems, especially for the building occupants. Radionuclides such as radium are very dangerous as they can settle in human bones. A similar risk also is posed by thorium which entered the lungs and bones as dust or other materials of the building occupants (19-20). The potential hazards of external radiation such as gamma rays likely depend on the amount of time the building occupants spend in the room (8).

Several studies have been conducted in Indonesia to examine the natural radionuclides caught in the marine compartment and their potential risk to humans' health (21). However, there is still no study that specifically addresses the amount of radioactivity levels in building materials. Therefore, a more in-depth study of the potential of radiological hazards caught in the sand is needed when used as a building material. This study is expected to be useful, especially for every occupant of the building.

This study discussed the amount of natural radionuclide activity found in beach sand from Madura, Bali, and Lombok. In addition to that, it also addressed the potential radiological risks to humans health, which can be helpful references for relevant decision-makers.

METHODS

Analysis of ^{226}Ra, ^{232}Th and ^{40}K Radionuclides

The sampling was carried out at several points on the coasts of Madura, Bali, and Lombok islands in 2016. These three islands located adjacent to the island of Java, where Madura is in the Northeast of Java while Bali and Lombok were close to each other. The sample was taken randomly and spread using a grab sampler. There were 11 points selected as samples where each point was taken approximately 1.5 kg of beach sand.

The sand samples were tightly wrapped in plastic clips, labelled, and taken to the laboratory for preparation. The sample would be dried using an oven (Memmert, Germany) at 80°C for several days to remove the moisture. After that, the samples were crushed and sieved, then stored in Marinelli as much as 1 kg and tightly closed for 28 days to ensure the equilibrium between the ^{226}Ra and ^{232}Th nuclides. Samples stored then measured using a Gama High Purity Germanium (HPGe) detector with a relative efficiency of 20-25% for three days to detect gamma radiation emitted from the samples. During the measurement process, the samples were contained with lead to minimize the natural radiation interference around the laboratory. The detector machine was routinely and periodically calibrated based on CRM (Certified Reference Material) Europium (152Eu) to ensure the measurement runs accurately. Moreover, the detector's background radiation value was also set before the measurement process.

The samples had been measured for three days, calculated using the Genie 2000 Gamma Acquisition & Analysis application to enumerate gamma spectrum energy would produce in the form of energy peaks that represent the radioactive substances contained in the samples. The activity of ^{226}Ra could be identified at low energy of 186.2 keV. Moreover, the activity of ^{226}Ra could also be calculated through its decays, ^{214}Pb and ^{214}Bi, at energies of 295.2, 351.9 keV (^{214}Pb) and 609.3, 768.3, 934.1, 1120.3, 1238.1, 1764.5 keV (^{214}Bi), after 28 days when they reached the equilibrium. Further, the activity of ^{232}Th could also be calculated through its decays, ^{228}Ac and ^{212}Pb, at energies of 209.2, 328.0, 409.5, 463.0, 794.9, 835.7, 911.2, 964.7, 968.9 and 300.1 keV. The characteristics of ^{226}Ra and ^{232}Th are different from ^{40}K which could be seen directly without the help from its decays due to its abundance in nature. The activity of ^{40}K could be seen at an energy of 1460.8 keV (10,22).

Literature on Radiation Dose

To understand how big the hazards, there were several assessed indicators such as the activity value of radium equivalent (Ra_{eq}), gamma activity concentration index (I), as well as external (H_{ex}), and internal (H_{in}) hazard indexes.

Ra_{eq} was used as a marker for both evaluation and prediction of radiation exposure based on radiation dose. It was different from hazard criterion I, which is the most commonly used indicator, especially for building materials. The results of Ra_{eq} analysis were used to

regulate the building materials. All building materials must not produce an effective annual dose of more than 1 mSv to the building occupants.

Meanwhile, the H_{ex} was used to see the level of external exposure received by the building occupants in a certain period. This was different from the H_{in} which is used to see the level of internal exposure received by humans due to radionuclides that enter through breathing or food (12,23). The following formulas were used to calculate Ra_{eq}, I, $H_{ex,}$ and H_{in} in this study: (24-25)

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_{K} \qquad (1)$$
$$I = A_{Ra}/150 + A_{Th}/100 + A_{K}/1500 \qquad (2)$$
$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_{K}/4810 \qquad (3)$$
$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_{K}/4810 \qquad (4)$$

With these formulas, this study could calculate the amount of radiation found in a building and evaluated the radiological hazards potentially received by individuals occupying a building (12,18).

RESULTS

The Activity of ^{226}Ra, ^{232}Th and ^{40}K Radionuclides

The results of the radionucleid activity as shown in Table 1. The activity of ^{226}Ra, ^{232}Th, and ^{40}K found in the coast of Madura ranged from 27.28 Bq/kg to 37.86 Bq/kg, 36.47 Bq/kg to 46.9 Bq/kg, and 257.20 Bq/kg to 451.99 Bq/kg with an average of 31.46, 40.12 and 334.04 Bq/kg for each radionuclide. In addition, the activity of these radionuclides found on the coast of Bali ranged from 21.06 Bq/kg to 31.13 Bq/kg, 6.155 Bq/kg to 8.785 Bq/kg, and 145.89 Bq/kg to 183.45 Bq/kg with an average of 25.10, 7.71 and 165.15 B/kg for each radionuclide. Meanwhile, for the Lombok's coast, the activity ranged from 18.18 Bq/kg to 32.52 Bq/kg, 6.38 Bq/kg to 10.02 Bq/kg, and 150.31 Bq/kg to 189.94 Bq/kg with an average of 25.88, 8.25, and 171.99 Bq/kg.

The Evaluation of Hazardous Radiological Effects

This result of estimated the potential radiological hazards of Ra_{eq}, I, H_{ex}, and H_{in} as shown in Table 4. The highest value of Ra_{eq} was found in Madura beach sand with ranged from 101.19 Bq/kg to 132.72 Bq/kg. Meanwhile, Bali have the smaller Ra_{eq} than Madura. Lombok has the smallest Ra_{eq} with ranged from 41.33 Bq/kg to 55.92 Bq/kg. As for parameter I, Madura ranged from 0.73 to 1.02 while Bali and Lombok ranged from 46.07 to 54.06 and 41.33 to 55.92. As for parameter H_{ex}, Madura, Bali, and Lombok ranged from 0.27 to 0.38,

0.12 to 0.15, and 0.11 to 0.15 respectively. As for last parameter H_{in}, Madura, Bali and Lombok ranged from 0.35 to 0.48, 0.18 to 0.23 and 0.16 to 0.24 respectively.

Table 1. Natural Radionuclide Activity in Madura, Bali, and Lombok

Sample	Location	Radionuclide (Bq/kg)		
		^{226}Ra	^{232}Th	^{40}K
Madura 1	112⁰ 40' 22.8"E 7⁰ 2' 38.4" S	37.86 ± 4.47	46.9 ± 6.2	451.99 ± 79.41
Madura 2	113⁰ 6' 39.6"E 6⁰ 52' 12"S	29.24 ± 3.44	36.47 ± 4.84	257.20 ± 45.19
Madura 3	113⁰ 25' 48"E 7⁰ 13' 15.6"S	27.28 ± 3.21	36.98 ± 5.8	292.94 ± 51.46
Bali 1	115⁰ 18' 35.11"E 8⁰ 52' 39.69"S	23.13 ± 3.87	8.185 ± 0.45	145.89 ± 16.98
Bali 2	114⁰ 58' 9,03"E 80 36' 22.4"S	21.06 ± 2.31	8.785 ± 0.94	166.13 ± 17.32
Bali 3	114⁰ 45' 57.35"E 8⁰ 28' 3.73"S	31.13 ± 4.01	6.155 ± 0.36	183.45 ± 19.42
Lombok 1	115⁰ 57' 48.38"E 8⁰ 27' 24.60"S	30.88 ± 1.35	6.38 ± 0.34	189.94 ± 3.28
Lombok 2	115⁰ 58' 47.7"E 8⁰ 40' 7.25"S	32.52 ± 4.12	8.27 ±0.42	150.31 ± 10.13
Lombok 3	116⁰ 8' 40.97"E 8⁰ 59' 59.24"S	25.32 ± 31.51	10.02 ± 0.51	182.32 ± 11.81
Lombok 4	116⁰ 35' 52.44"E 8⁰ 47' 7.5"S	18.18 ± 2.49	7.24 ± 0.35	166.29 ± 14.07
Lombok 5	116⁰ 16' 45.46"E 8⁰ 11' 55"S	22.52 ± 2.98	9.32 ± 0.55	171.12 ± 15.34

Table 2. Comparison of Activity Concentrations (Bq/kg) at ^{226}Ra, ^{232}Th, and ^{40}K in the Coastal Environment in Indonesia

Location	^{226}Ra		^{232}Th		^{40}K		References
	Range	Mean	Range	Mean	Range	Mean	
Madura	27.28-37.86	31.46	36.47-46.9	40.12	257.20-451.99	334.04	This work
Bali	21.06-31.13	25.10	6.155-8.785	7.71	145.89-183.45	165.15	This work
Lombok	18.18-32.52	25.88	6.38-10.02	8.25	150.31-189.94	171.99	This work
Bengkalis	25.01-109.62	56.45	16.03-49.80	30.67	99.39 - 255.93	185.49	(35)
Jakarta	42.0-64.92	51.44	-	-	-	-	(20)
Sluke	66.07-95.24	76.70	-	-	160.54-503.87	365.79	(21)
Kalimantan	1.09-53.46	-	1.25-32.91	-	28.58-596.83	-	(36)

Table 3. Comparison of Activity Concentrations (Bq/kg) at ^{226}Ra, ^{232}Th, and ^{40}K on Beach Sand from Several Countries

Location	^{226}Ra		^{232}Th		^{40}K		References
	Range	Mean	Range	Mean	Range	Mean	
Madura, Bali and Lombok	18.18-37.86	27.48	6.16-46.9	18.69	145.89-451.99	223.73	This work
Thailand	1.6-83.1	22.6	0.3-73.9	26.4	1.9-1376	523.0	(10)
Bangladesh (Whitesand)	33.3-63.3	49.4	60.8-82.5	71.6	832.4-1046.1	927.2	(18)
Bangladesh (Redsand)	46.0-67.4	59.2	65.6-94.6	82.0	889.3-1136.2	1035.6	(18)
Gran Canaria, Spain (S)	8.1-26.7	17.1	7.4-41.9	20.4	130-1055	460.21	(11)
Gran Canaria, Spain (D)	6.5-29.7	18.2	6.5-40.6	22.3	83-972	501	(11)
Tamilnadu State, India	-	-	BDL-2938.31	26.32	BDL-570.04	202.87	(12)
Guangxi Province, China	4.88-9.43	7.07	-	-	2.76-109.16	28.94	(33)
Southern India	1.56-32.38	-	34.77-229.30	-	5.21-88.39	-	(34)
Langkawi Island, Malaysia (Black Sand)	451.4-2411.4	1478.1	232.2-1271.9	718.3	60.9-135.6	102.7	(22)
Langkawi Island, Malaysia (White Sand)	8.3-13.7	9.8	4.5-9.4	5.9	84.6-132.5	101.7	(22)
Turkey	BDL-65	-	BDL-28	-	9-1936	-	(37)
Temsah Lake Beach, Egypt	4.29-30.06	9.57	6.96-39.24	13.77	37.17-242.25	141.64	(14)

Table 4. Calculation of Radiological Hazard Index Values in Beach Sands of Madura, Bali, and Lombok, Indonesia

Location	Ra_{eq} (Bq/kg)	I	H_{ex}	H_{in}
Madura 1	139.72	1.02	0.38	0.48
Madura 2	101.19	0.73	0.27	0.35
Madura 3	102.71	0.75	0.28	0.35
Bali 1	46.07	0.33	0.12	0.19
Bali 2	46.41	0.34	0.13	0.18
Bali 3	54.06	0.39	0.15	0.23
Lombok 1	54.64	0.40	0.15	0.23
Lombok 2	55.92	0.40	0.15	0.24
Lombok 3	53.69	0.39	0.15	0.21
Lombok 4	41.33	0.30	0.11	0.16
Lombok 5	49.02	0.36	0.13	0.19
Recommended Values	<370	<0.5	<1	<1
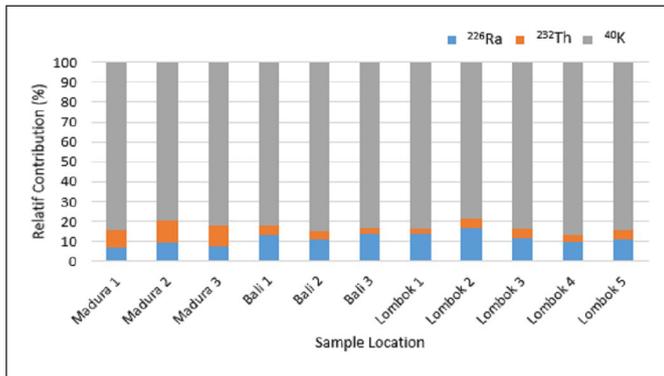
Figure 1. Relative Concentrations of ^{226}Ra, ^{232}Th and ^{40}K to Total Activity
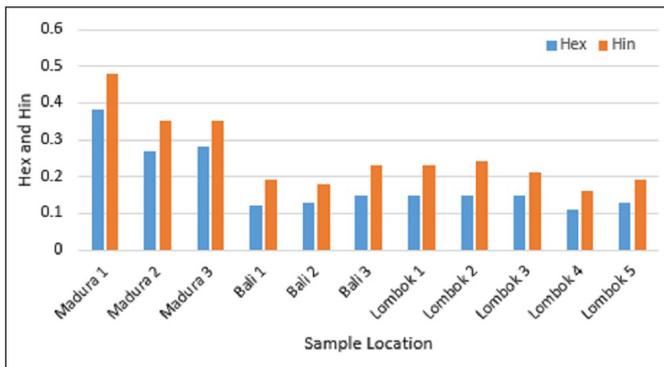
Figure 2. External and Internal Hazard Indices on Beach Sand Samples
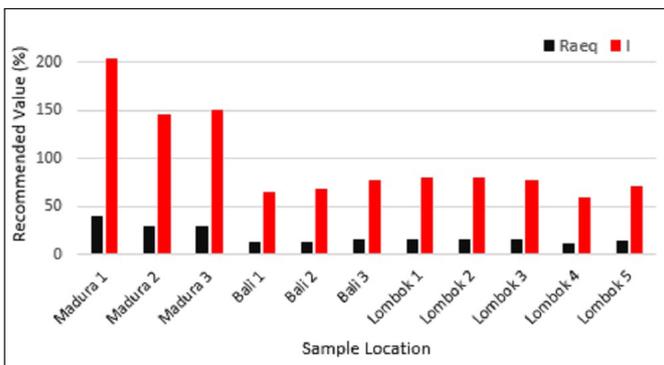
Figure 3. Recommended Value (%) of Ra Equivalent and Gamma Activity Concentration Index in the Sample

DISCUSSION

The Concentration of ^{226}Ra, ^{232}Th and ^{40}K

These study findings showed that the characteristic of radionuclides activity from ^{226}Ra was found in Madura, Bali, and Lombok slightly differed from each other. Meanwhile, the characteristics of ^{232}Th found that Madura beach sand was considered to have four times higher concentration compared to Bali and Lombok. These radiological variations can be influenced by geological conditions and drainage patterns in each location. The high concentration of the radionuclides found in the beach sand may be due to the continuous deposition of minerals via sea waves (26).

The activity of ^{40}K radionuclide has the most extensive activity and contribution, followed by ^{226}Ra and ^{232}Th. The abundance of ^{40}K is due to the richness of continental rocks, and it is found in high concentrations in many light minerals. As possible that ^{40}K remains the dominant isotope found in soil originating from primary weathering (23). Although ^{40}K occurs naturally in soil, its concentration may be formed by the disposal of liquid, air, solid wastes, or industrial waste that produces naturally radioactive materials (NORMs) such as oil, gas production, and many conventional mining and milling industries. Besides, the extensive use of phosphate fertilizers in cultivated soils can also be a potential source of natural radionuclides (27).

This study found that the activity of ^{40}K in Madura was twice as much as Bali and Lombok. It might cause that the sand composition in Madura had more organic minerals. The nature of sand absorbs lower radionuclides compared to other organic matters found in soil (23).

Meanwhile, the activity of ^{226}Ra and ^{232}Th was considered higher in almost all samples. Except for Madura, it was considered lower. The differences were caused by chemical speciation or their abundance in the natural environment. Additionally, the absorption behavior of ^{226}Ra and ^{232}Th in marine environmental compartments, such as coastal sands and sediments, depends on pH. ^{226}Ra is usually more absorbed in organic or clay content, especially at pH conditions close to neutral to alkaline (28). Thus, the measured activity of ^{226}Ra and ^{232}Th in the beach sand is highly dependent on the organic or clay content in the sand. The higher the organic or clay content in the sand, the higher the ^{226}Ra adsorbed on the beach sand.

Looking at the overall activity data, the activity of ^{226}Ra, ^{232}Th, and ^{40}K nuclides in Bali and Lombok had almost similar values. It was reasoned that Bali and Lombok are geographically close, which accounts for their almost identical characteristics. Table 2 represents the comparison of the natural radionuclide data across Indonesia. It was found, in general, that there was no significant difference between the radionuclide activity in this study and other regions in Indonesia.

The type of sand also influences the variation of radionuclide activity found in beach sand. A study in Douala Littoral, Cameroon, stated that different types of sand account for different radionuclides activity to used in building materials (9). Another study conducted in Northwest China discussed the magnitude of the natural radionuclide activity of various aggregates used as building materials. The study mentioned that the different

aggregates of building materials account would reach varying radiation levels to building occupants (29).

Table 3 represents the comparison of the natural radionuclide activity in the sand in several other countries. Our study result compared to Bangladesh and Thailand showed that the activity of ^{226}Ra in 18.18 - 37.86 Bq/kg tended to be smaller considering that Bangladesh had 33.3 to 67.4 Bq/kg and Thailand had 1.6 - 83.1 Bq/kg (10,18). Even our result was still under the threshold limit value when compared United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) standard (30). It was indicated that the ^{226}Ra activity in our study still at a safe level and considered lower than several other countries such as Bangladesh (18).

Moreover, the activity of ^{40}K in this study still considered lower if compared to other countries such as Thailand (10), Bangladesh (18), and Spain, which had the highest average value (11). Comparing the three natural radionuclides in the study with other countries, the sand beaches in Madura, Bali, and Lombok are still safe. The activities are not much different from the average of other countries.

The Evaluation of Hazardous Radiological Effects

The average activity values of ^{226}Ra, ^{232}Th and ^{40}K in this study could not provide a direct indication of the radiation hazards associated with the use of beach sand as a building material. Further radiological calculations need to be done using a predetermined formula. After that, compared with safe limits recommended by the international standards.

Table 4 suggests the calculation and analysis of radiological hazards posed by beach sand. Our findings showed that the beach sand in Madura had a higher average Ra_{eq} value (114.54 Bq/kg) compared to Bali (48.85 Bq/kg) and Lombok (50.92 Bq/kg). However, the Ra_{eq} values of the three selected locations were still far below the safe limit of 370 Bq/kg (25).

Ra_{eq} activity was used to compare ^{238}U, ^{232}Th, and ^{40}K in beach sand with one quantity. The evaluation of Ra_{eq} was based on the assumption that 370 Bq/kg of ^{238}U, 259 Bq/kg of ^{232}Th, and 4810 Bq/kg of ^{40}K produce the same dose of gamma radiation. The Ra_{eq} value can be helpful for guidance to protect the population from radiation exposure (31).

The evaluation of radionuclides' activity also includes the analysis of gamma activity concentration index (I). The gamma index serves as a screening tool for building aggregates that may affect occupant health and potentially cause stochastic effects (32). For building

materials to be considered radiologically safe, the value of I value should correspond to the annual effective dose threshold (≤ 1 mSv), while the value of Iγ ≤ 0.5 corresponds to the annual effective dose (≤ 0.3 mSv) (31). The average gamma activity concentration index for beach sand in Bali and Lombok is 0.35 and 0.37, respectively. This value can meet the limit value of less than 0.5 (33). Meanwhile, the value of I in Madura was 0.83, which exceeds the safe limit (> 0.5). Even at the sampling point with the code, Madura 1 had a value of 1.02 (I > 1).

It was understood that the beach sands in several other countries such as the Guangxi Province, China, and white sand in Langkawi, Malaysia had a slightly smaller average I value of 0.17 and 0.19 (22,34). However, there was also a report that the beach sand in other areas such as Southern India had a higher value of I (2.35) than this study (35). Even black sand on the island of Langkawi, Malaysia, had a 17-time higher I value (17) than in this study (22). There should be no deterministic effect of radiations since this condition will only occur if the occupant is exposed to doses exceeding 1 Sv. However, the risk of stochastic effect will increase along with the increase of Iγ value. Therefore, the use of beach sand as a building material should be avoided (I > 1) to reduce the possibility of stochastic effect (12,18).

External and internal radiations to ^{238}U, ^{232}Th, and ^{40}K present in the sand are referred to as the external hazard index (Hex) and the internal hazard index (Hin). The external hazard index refers explicitly to the evaluation of the natural gamma radiation hazard. This index is used to assess the radiological suitability of material. The main purpose of this index is to limit the radiation dose to an acceptable dose limit of 1 mSv/y (26). While the external exposure results from direct gamma radiation, the internal exposure results from the inhalation of radon gas and short-lived decay products trapped in building enclosures. Radon gas (^{222}Rn) is a short-lived gas threatening human respiratory organs (31). The gamma radiation hazard is negligible if the Hex and Hin values must be less than 0.5.

Based on the analysis of the external (Hex) and Internal (Hin) hazard indexes, the average Hex values in Madura, Bali, and Lombok were 0.31, 0.13, and 0.14, while the average Hin values were 0.39, 0.2, and 0.2. It can be concluded that the three selected locations are safe (33). According to Table 2, it was found that the Hin values were higher than Hex values. Therefore, special treatment should be prepared to prevent this sand enter the occupant's body. The use of 80% natural ventilation and 20% artificial ventilation, such as an Air Conditioner,

can be a solution to reduce the impact of radiation on building occupants (7).

In conclusion, only one out of four radioactive hazard indicators in Madura exceeded the safe limit. Several previous studies suggested if an I-value was > 0.5, then the use of beach sand as a building material should be avoided even though several other studies considered it safe. Therefore, a more in-depth study is required for the use of beach sand on Madura Island. Meanwhile, the beach sand in Bali and Lombok is considered safe. This is reasonable since all-hazard indicators in Bali and Lombok are still below safe limits.

CONCLUSION

The activity of the three types of natural radionuclides was still below the recommended value. The potential radiological hazards of beach sand in Bali and Lombok were still below the safe limit. Meanwhile, it was found that the gamma index value (I) in Madura exceeded the safe limit. Although the other three hazard indicators in Madura are considered safe, a more in-depth study is required for the use of beach sand on Madura Island.

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