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Determination of radioactivity levels and radiological risk factors in bozcaada-canakkale, turkey

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► ***Original article***

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ABSTRACT

Background: Natural radiation is radiation that comes from two main environmental sources, the cosmic radiation from space that passes through the atmosphere, and terrestrial radiation is created when radionuclides decay in rock and soil. The most important radionuclides forming the natural radioactivity in terrestrial sources are ^{40}K, ^{238}U and ^{232}Th. ***Material and Methods:*** In this study, ^{137}Cs, ^{40}K, ^{238}U and ^{232}Th activity levels were measured in samples taken from different parts of the island and beaches to determine the environmental radioactivity of Bozcada-Çanakkale using gamma spectrometry with a NaI(Tl) detector and radiation hazard indexes were calculated for soils. ***Results***: Average activity concentrations of ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs in soils were obtained as 427, 24, 31, and 29 Bqkg^{-1}, respectively. The average activity values for ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs in beach sands were determined to be 329, 23, 11 and 14 Bqkg^{-1}, respectively. Radiological risk factors for Bozcaada soils were calculated. ***Conclusion:*** Our results were compared with the literature data and average world limit values. As a result of this study, we can state that the activity concentrations of Bozcaada Island beach sands are lower than the activity concentrations of soils. Since Bozcada is an island that attracts tourists, the low radionuclide activity in the beach sands shows that this place does not pose a significant radiological threat to peoples.

INTRODUCTION

There are two types of radiation sources: natural and artificial. Natural radiation has been with us since the beginning of the time. Radiation can be found in a wide variety of geological formations in our globe, including the earth's crust, rock, soil, flora and air [(1)].

Natural radiation is radiation that comes from two main environmental sources, the cosmic radiation from space that passes through the atmosphere and terrestrial radiation is created when radionuclides (radioactive isotopes) decay in rock and soil [(2,3)]. The most important radionuclides forming the natural radioactivity in terrestrial sources are ^{238}U, ^{232}Th and ^{40}K radionuclides [(4,5)].

In fact, all rocks contain low levels of natural radioactivity that are caused by the decay of radionuclides that are find in small concentrations in the range of parts per million (ppm). The natural radiation levels of the rock and soil depend on the radionuclide concentrations and specific radionuclide activities (the amount of decay per unit time and mass).

Natural radiation in soils and rocks depends on the mineralogical components of the soil. The natural radioactivity in the rock and soil can vary greatly from soil to soil, depending on the mineral configuration of each specific geological formation [(4,6)]. High potassium, uranium, and thorium concentrations in rocks result in a relatively higher natural radioactivity. The radioelement concentrations of the parent rocks can be seen in soils [(2)]. In the world we live in, natural radionuclide concentrations and distributions are not constant because they have different concentrations in different regions. Natural radiation in an area varies depending on the geological structures of that region, including soil structure, soil formations, and soil properties [(7)].

Radiation in soil may result from the presence of natural radioactive materials. This level of radiation can cause health problems when in contact with humans. It can lead to serious health problems such as cancer, especially in cases of long-term and high-level exposure [(4)].

Humans are exposed to cosmic rays, which are part of natural radiation and radionuclides in terrestrial radiation, as well as artificial radiation from nuclear fallout and medical treatments. 80 % of the human dose comes from natural radionuclides, and 20 % comes from nuclear processes and cosmic rays [(1)].

People and other living things are always exposed to natural radiation from cosmic rays and radionuclides situated in soil, water and food [(8)].

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These radiation sources are a natural phenomenon caused by environmental factors. Human exposure to natural radiation may vary depending on a variety of factors. The natural radiation exposure level of humans is generally stated as mean effective dose of 2.4 mSv per year. Estimates suggest that 65% of people are exposed to an annual effective dose between 1-3 mSv, while 25% are exposed to an annual effective dose below 1 mSv and 10% are exposed to an annual effective dose above 3 mSv (4).

It is important to forecast the effects of natural radiation exposure on cancer risk and to reduce these risks. This is necessary to make effective decisions in health-related applications. Effective dose equivalent is an important tool for assessing and controlling radiation-related risks and plays a critical role in health and environmental protection.

Bozcada is a district of Çanakkale province and is the third largest island of Turkiye. It is the second largest island in the Aegean Sea after Gökçeada (9). It has been an important island in terms of tourism since 1990. This work aims to determine the natural radioactivity levels of Bozcada and to evaluate radiological risk factors such as radium equivalent (Ra_{eq}), air absorbed gamma dose rate (D), annual effective dose (AEDE), annual gonadal dose equivalent (AGDE), excess lifetime cancer risk (ELCR), internal radiation hazard index (H_{in}), and external radiation hazard index (H_{ex}). It is aimed to determine the radiation hazard index on Bozcada Island and to establish a reference line for subsequent studies on NORM in Çanakkale. Such studies are crucial for monitoring the environmental impact of radioactivity and ensuring that radiation levels remain within acceptable limits. The results may also contribute to the understanding of natural background radiation in the island and the assessment of possible impacts from human activities or natural sources.

MATERIAL AND METHODS

The study area

The island of Bozcaada is situated 12 nautical miles south of the Dardanelles Strait in the northeastern Aegean Sea. The area of Bozcaada, which is 38 km in circumference is 36.67 km^2 and has a surface area of 37.6 km^2, including 17 small and large islets around it (11). The island center is located on the east side of the island at approximately 39° 50' N and 26° 04' E (figure 1). Bozcaada is 7.5 kilometers from Geyikli, the nearest port in the Dardanelles strait's south. The highest point of the island is Göztepe (192 meters) (9). Bozcaada is generally low and flat in terms of landforms. The island generally consists of wide plains. There are 12 capes and 2 bays on the island. There are also sand dunes on the northern coast. The Mediterranean climate is present in Bozcaada. It is windy in all months of the year. It gets a lot of north winds, especially in the winter, but is also open to south winds (10).

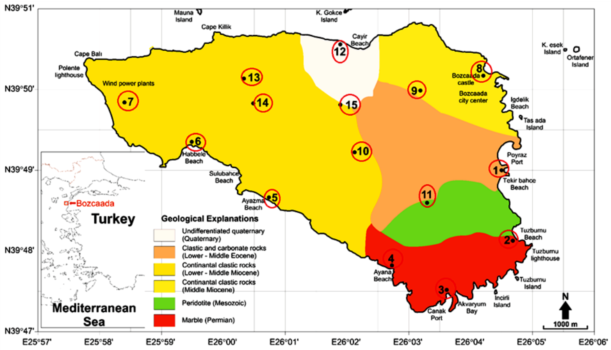

Figure 1. Geological map of Bozcaada Island and the sampling locations (sampling points are circled in red) (11).

At the northeastern edge of Bozcaada Island, there is andesite, a volcanic rock dating back to the Middle Miocene. The western part and the general part of the island are formed by sedimentary rocks belonging to the lower middle Miocene period. In the eastern part of the island, clastics and carbonates from sedimentary rock groups are observed. Towards the south of the island, there are peridotites, which are ophiolitic rocks and marbles, which are metamorphic rocks (figure 1).

In Bozcaada, there are units that start with metashales and calcschists, continue upwards with alternating metashale and recrystallized limestone metashale, and transition to gray-black thick-bedded massive limestones at the top. Upper Permian-aged fossils were found within the recrystallized limestones with a thickness of about 1600 m. Over these are ophiolitic units, mostly composed of serpentinized peridotites with tectonic contact. The Eocene units, which start with red-colored conglomerates, come above. Towards the top, there are gray-colored conglomerates and gray-white limestones containing abundant Middle Eocene-aged fossils. Above these are Eocene flysch-structured conglomerate, sandstone, marl, claystone and limestone levels. These units are cut by andesite and dacite-type lavas, and it was determined that they are of Lower Miocene age with the radiometric age measurement made in this study. Over these are lacustrine deposits of Middle upper miocene aged conglomerate, claystone, marl, sandstone and limestone intercalations and the uppermost is Quaternary. There are old alluviums (12).

Radioactivity measurements

To determine the artificial and natural radionuclide levels of Bozcaada Island, 15 soils were collected from diverse sampling points and beach sands were collected from 7 beaches of Bozcaada (Tekirbahçe beach, Tuzburnu beach, Akvaryum beach, Ayana beach, Ayazma beach, Habbele beach and Çayır beach). Geographic coordinates of samples

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were obtained using a Garmin GPS navigator. Sample codes, coordinates and place names of the samples collected from Bozcaada Island are listed in table 1.

Table 1. Localities, geographical coordinates and codes of soil and beach sand samples (S:Soil, BS: Beach Sand).

Sample No	Localities	Coordinates		Samples Codes	
		Latitude (N)	Longitude (E)	Soil (S)	Beach Sand (BS)
1	Tekir bahçe beach	39.81652°	26.07459°	S1	BS1
2	Tuzburnu beach	39.80160°	26.07885°	S2	BS2
3	Akvaryum beach	39.79166°	26.06035°	S3	BS3
4	Ayana beach	39.79741°	26.04539°	S4	BS4
5	Ayazma beach	39.81169°	26.01140°	S5	BS5
6	Habbele beach	39.82232°	25.99107°	S6	BS6
7	Power plant	39.82941°	25.97585°	S7	-
8	Bozcaada castle	39.83622°	26.07093°	S8	-
9	Petrol station	39.83232°	26.05394°	S9	-
10	Ayazma Tuzburnu distinction	39.82010°	26.03412°	S10	-
11	Tuzburnu-icece distinction	39.80862°	26.05581°	S11	-
12	Çayır	39.84283°	26.03163°	S12	BS12
13	Deliimam	39.83479°	26.00723°	S13	-
14	Habbele	39.82917°	26.00825°	S-14	-
15	Amerikan Fountain	39.83014°	26.03184°	S15	-
Total Samples				**15**	**7**

Soil and sand samples totaling 1500 g were taken from a depth range of 5 to 15 cm in Bozcaada. The samples were cleaned of any rocks, roots, or other plants before being put in plastic bags. The laboratory received samples that had been tagged with the sampling locations. The moisture was then removed by drying it for 24 hours at 80 °C, followed by sieving. Samples weighing 100 g were put into polyethylene beakers, sealed, and given four weeks to allow the parent radionuclides (^{232}Th and ^{238}U) and their related children to equilibrate. To calculate the overall activity of ^{137}C, soil and beach sands were additionally weighed at 1 kg and placed in Marinelli beakers.

An ORTEC-905-4 gamma spectrometer with 3'' × 3'' NaI (Tl) detector was used to measure each samples. For system calibration. CNAEM's (Cekmece Nuclear Research and Training Center of Turkish Atomic Energy) radioactive ^{137}Cs standard source, eU standard sample of 136 ppm, eTh standard sample of 600 ppm, and a K standard sample of 52.4 % were employed. The peak of ^{137}Cs (662 keV), the peak of ^{40}K (1460 keV), the peak of ^{214}Bi (1760 keV) and the peak of ^{208}Tl (2610 keV) were employed in this study for the quantitative determination of ^{137}Cs, ^{40}K, ^{238}U and ^{232}Th, respectively. Every sand sample was counted for two hours. The collected spectra were used to calculate the net integral counts. It was computed the activity concentrations as Bq kg^{-1}.

The Radiological Hazard Parameters
Radium equivalent (Ra_{eq})

Ra_{eq} is known as the common radiological hazard index. Ra_{eq} is employed to estimate the activities of ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th in the samples as well as the radiation risks associated with each component ^{40}K, ^{226}Ra and ^{232}Th) (13,14). It was determined mathematically by using equation (1) (3,4,5):

$$Ra_{eq} = A_{Ra} + 1.43 \times (A_{Th}) + 0.077 \times (A_K) \quad (1)$$

A_K, A_U and A_{Th} are the activities of potassium, uranium, and thorium, (Bq kg^{-1}), respectively. It is accepted that gamma dose from ^{40}K of 130 Bq kg^{-1}, ^{226}Ra of 10 Bq kg^{-1} and ^{232}Th of 7 Bq kg^{-1} are equal in the equation (1) (15).

Absorbed gamma dose (D)

D is a term that measures of the gamma radiation amount released by radionuclides to which a material is exposed per unit mass and unit time (16). D was computed using the equation (2).

$$D(nGy\ h^{-1}) = 0.462(A_U) + 0.604(A_{Th}) + 0.0417(A^K) + 0.1243(A_{Cs}) \quad (2)$$

A_{Cs} is the activity of ^{137}Cs, (Bq kg^{-1}). The related dose constants found in the scientific literature are 0.0417, 0.1243, 0.462 and 0.604 nGy h^{-1}/Bq kg^{-1}, respectively (17,18).

Annual effective dose equivalent (AEDE)

AEDE is a weighted sum of the doses to various organs, each weighted according to its radiation sensitivity (8,16). It was calculated using the equation (3) (4,5):

$$AEDE\ (mSv\ y^{-1}) = D(Gy\ h^{-1}) \times DCF(SvGy^{-1}) \times 8760(hy^{-1})\ \ 0.2 \times 10^{-6} \quad (3)$$

The 0.7 is the dose conversion constant. It is converted the absorbed dose (Gy) into effective dose (Sv). The outdoor occupancy factor (OOF) is 0.2 (4,16,18). This factor represents the proportion of time an individual is expected to spend outdoors.

Annual Gonadal Dose Equivalent (AGDE)

The AGDE represents the annual equivalent dose received by the gonads (reproductive organs) as aresult of exposure to ionizing radiation. It was calculated utilizing the equation (4) (13,16):

$$AGDE(\mu Sv\ y^{-1}) = 0.314 \times (A_K) + 3.09 \times (A_{Ra}) + 4.18 \times (A_{Th}) \quad (4)$$

Excess lifetime cancer risk (ELCR)

The ELCR is a measure used to determine the likelihood of developing cancer over a given lifetime because of exposure to ionizing gamma radiation (16). It was found with the equation (5) (5,19,20):

$$ELCR = (AEDE) \times (DL) \times (RF) \quad (5)$$

DL (the duration of life) is 70 years. RF (the risk factor), representing the lethal cancer risk per Sv is 0.05 Sv^{-1}. The 0.05 value is used for stochastic effects

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on people by the ICRP 60 (16, 17).

Internal Radiation Hazard Indices (H_{in})

H_{in} is a dimensionless index used to measure the possible radiological risk associated with internal exposure to radon and its decay radionuclides in building materials (16). It was determined by using the equation (6):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

External Radiation Hazard Indices (H_{ex})

H_{ex} is a dimensionless index used to evalute the potential radiological risk associated with external exposure to gamma radiation from materials. It is characterized by equation (7):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

Where, the values of H_{in} and H_{ex} must be less than 1 (16,18).

Statistical analysis

The mean, standard deviation and frequency distribution graphs of the ^{40}K, ^{238}U and ^{232}Th activity results in this study were made using by a statistical package of social sciences (SPSS20) program. Correlation-test was used to calculate the degree of significance between the obtained data.

RESULTS

Activity concentrations

Specific activities of soil and beach sands collected from different points of Bozcada were measured. Data for each sample were calculated cumulatively by counting on agamma spectrometer for two hours to determine activity concentration. The potassium, uranium, thorium and cesium activities of all samples are given in tables 2 and 3. Frequency distribution graphs for ^{40}K, ^{238}U and ^{232}Th activity results in present study were given figure 2.

Table 2. Activities in soils collected from Bozcaada-Çanakkale (Bq kg^{-1}). (LLD: Low level detection, IS: Insufficient sample).

Sample No	Activity Concentrations			
	^{40}K	^{238}U	^{232}Th	^{137}Cs
1	255.5 ± 16.0	25.1 ± 5.0	25.8 ± 5.1	IS
2	680.7 ± 26.1	23.4 ± 4.8	36.3 ± 6.0	28.1 ± 5.3
3	442.0 ± 21.0	8.8 ± 3.0	36.3 ± 6.0	IS
4	415.5 ± 20.4	6.2 ± 2.5	21.5 ± 4.6	IS
5	500.3 ± 22.4	48.4 ± 7.0	25.6 ± 5.1	IS
6	224.3 ± 15.0	50.1 ± 7.1	22.5 ± 4.7	IS
7	514.9 ± 22.7	12.4 ± 3.5	LLD	15.0 ± 3.9
8	382.5 ± 19.6	25.8 ± 5.1	65.7 ± 8.1	44.2 ± 6.7
9	452.1 ± 21.3	44.8 ± 6.7	36.5 ± 6.0	38.4 ± 6.2
10	483.5 ± 22.0	18.2 ± 4.3	32.5 ± 5.7	27.1 ± 5.2
11	603.0 ± 24.6	24.2 ± 4.9	54.0 ± 7.3	29.9 ± 5.5
12	432.0 ± 20.8	26.6 ± 5.2	54.7 ± 7.4	IS
13	429.4 ± 20.7	18.2 ± 4.3	25.3 ± 5.0	28.5 ± 5.3
14	347.2 ± 18.6	1.9 ± 1.4	15.5 ± 3.9	25.0 ± 5.0
15	236.6 ± 15.4	27.4 ± 5.2	8.6 ± 2.9	21.4 ± 4.6
Mean+SD	427 ± 127.6	24 ± 14.6	31 ± 17.6	29 ± 15.0

Table 3. Activities of beach sands collected from Bozcaada-Çanakkale (Bq kg^{-1}).

Sample Codes	Activity Concentrations			
	^{40}K	^{238}U	^{232}Th	^{137}Cs
BS1	106.2 ± 10.3	20.0 ± 4.5	11.7 ± 3.4	7.3 ± 2.7
BS2	625.7 ± 25.0	26.1 ± 5.1	4.5 ± 2.1	14.0 ± 3.7
BS3	245.6 ± 15.7	27.3 ± 5.2	6.9 ± 2.6	15.0 ± 3.9
BS4	285.1 ± 16.9	42.3 ± 6.5	3.8 ± 1.9	17.5 ± 4.2
BS5	295.4 ± 17.2	25.9 ± 5.1	7.4 ± 2.7	13.2 ± 3.6
BS6	269.2 ± 16.4	1.0 ± 1	14.1 ± 3.8	9.2 ± 3.0
BS12	476.3 ± 21.8	20.7 ± 4.6	30.6 ± 5.5	19.9 ± 4.5
Mean+SD	329 ± 169.8	23 ± 12.3	11 ± 9.3	14 ± 4.4

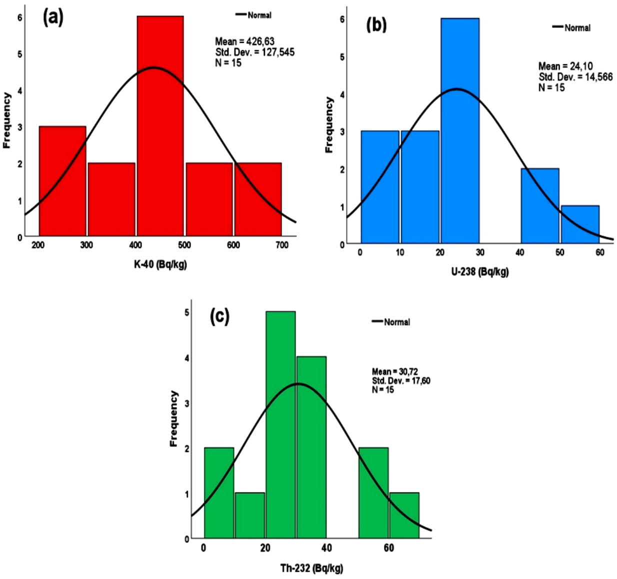

Figure 2. The frequency distributions of activity levels in Bozcaada soils: **a)** ^{40}K, **b)** ^{238}U, and **c)** ^{232}Th.

The ^{40}K activity levels in the soils were found in the range of 224.3 ± 15.1 to 680.7 ± 26.1 Bqkg^{-1} (table 1 and figure 2). While the average ^{40}K was 426.63 Bq kg^{-1}, the standard deviation of the samples for ^{40}K was calculated as 127.545 Bq kg^{-1}. The maximum value of ^{40}K was detected in S2 soil collected from the southeastern part of the island. It can be seen from the geological map that there are marbles in the geological structure of this region (table 2, figure 1). According to the frequency distribution graph of potassium activity, 60% of the soils (figure 2) had values that were more than the global average value (400 Bq kg^{-1} for ^{40}K) (4). The ^{238}U activity concentrations in soils ranged from 1.9 ± 1.4 Bq kg^{-1} to 50.1 ± 7.1 Bq kg^{-1} (table 2). The average uranium activity of the soils was 24.1 Bq kg^{-1}. The standard deviation of the uranium measurements was found to be 14.566 Bq kg^{-1} (figure 2). The lowest uranium activity was measured in S14 soil taken from the central part of the island, while the highest uranium activity was detected in S6 soil located in the southwest of the island. The maximum uranium activity in this study (50.1 Bq kg^{-1}) was determined to be 1.43 times the global average uranium value (35 Bq kg^{-1} for ^{238}U) (4). According to the graph of frequency distribution of uranium activity, 80 % of the soils have uranium activity between 1.9 and 35 Bq

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kg^{-1}, while 20 % of the soils (S5, S6 and S9) are greater than the mean world value (35 Bq kg^{-1}) (figure 2). The ^{232}Th activity was measured below the background in S7 soil taken from the west of the island. Thorium levels in other soils ranged from 8.6 ± 2.9 to 65.7 ± 8.1 Bq kg^{-1}. The mean thorium activity was 31 Bq kg^{-1}. The standard deviation of the mean thorium activity was 17.6 Bq kg^{-1}. The maximum thorium level was measured in S8 soil taken from the northeast of the island. This result was 2.19 times more than the global average value (30 Bq kg^{-1} for ^{232}Th) (4). Figure 1 shows that the geological structure of the region where S8 soil was taken has an andesite structure. Andesite is a stone of igneous origin. According to the frequency distribution graph drawn for thorium, the value of 46.6 percent of the soils are more than the global average value. In six of the soils, there weren't enough sample amount for ^{137}Cs measurement. Nine soils were examined, and ^{137}Cs activity in soils ranged from 15 ± 3.9 Bq kg^{-1} to 44.2 ± 6.7 Bq kg^{-1} with an average of 29 Bq kg^{-1}.

Table 3 displays the activity levels in the beach sands. ^{40}K activities in beach sands varies from 206.2 to 625.7 Bq kg^{-1}. The average potassium activity was calculated to be 329 Bq kg^{-1}. The sample with the highest potassium activity is the sample numbered BS-2 taken from the beach in the southeast of the island, which is 1.56 times the world mean value (400 Bq kg^{-1}) (4). Potassium activities in beach sands taken from the other 4 beaches are generally lower than the world average value. The uranium levels in the beach sands ranged from 1 to 42 Bq kg^{-1}, and the average uranium activity was calculated to be 23 Bq kg^{-1}. The BS4 sand taken from the southwest coast of the island has the highest activity. It is 1.2 times the global average value (35 Bq kg^{-1}). The values detected in other beach sands are under the world mean value for uranium. Thorium activities in beach sands ranged from 3.8 to 30.6 Bq kg^{-1} with an average activity 11 Bq kg^{-1} for ^{232}Th. Thorium levels in beach sands are generally below the world mean value of 30 Bq kg^{-1}, except for the BS12 sand. Cesium activities in beach sands varied from 7.3 to 19.9 Bq kg^{-1}. The average ^{137}Cs activity was calculated to be 14 Bq kg^{-1}. As a result, we can state that ^{137}Cs, an artificial radionuclide, was found in all beach sands. This shows that in addition to the natural radionuclides that make up environmental radioactivity, artificially existing radionuclides accumulate in environmental environments.

Figure 3, represents the percentage variation of the contribution of both artificial radionuclide and natural radionuclides to gamma radiation exposure. The average contribution by single constituents of natural radioactivity (^{40}K, ^{238}U, ^{232}Th) and artificial radioactivity (^{137}Cs) to the gamma-ray exposure is as follows: 86% from ^{40}K, 4% from ^{238}U, 4% from ^{232}Th, and 6% from ^{137}Cs, respectively (figure 3). This study shows that a significant amount of Bozcaada's contribution to environmental gamma radiation is provided by the gamma released from ^{40}K radionuclide.

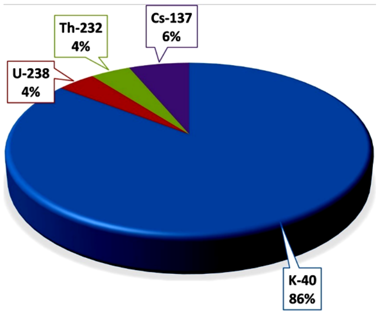

Figure 3. Percentage change graph of the contribution of natural and man-made radionuclides to Bozcaada's terrestrial gamma radiation exposure.

Radiological Risk Parameters

According to the data obtained from this study, the activity results in the soils taken from Bozcada island are higher than the activity results in the beach sands. Therefore, the activity results of soils were used for the radiological risk assessment of the Bozcada Island. Tthe radiological risk parameters for all soils were calculated using the equations (1–7) and our results are given in table 4. Table 4 shows that ^{226}Ra activities in soils range from 50.8 to 149.2 Bq kg^{-1}, with a mean value of 100.9 Bq kg^{-1}. Santos Junior *et al.* reported that the world average of radium for soil was 128.7 Bq kg$^{-1)}$ (21). The Ra_{eq} for all soils is below than 370 Bq kg^{-1} in the world (4). The results of D and AEDE for soils are given in figure 4. The absorbed gamma doses ranged from 24.7 to 68.9 nGy h^{-1}. The average absorbed gamma dose is 47.5 nGy h^{-1}. Except for S2, S8, S9, S11 and S12 soils, most of the other samples are lower than the global average value of 59 nGy h^{-1} (4). It is seen that the high value samples were taken from the east, southeast and central part of the island. The calculated AEDE values vary between 0.030 and 0.085 mSv y^{-1}. The mean AEDE was found to be 0.058 mSv y^{-1} (table 4). The results of this investigation (S2, S5, S8, S9, S11 and S12 soils) show that 40% of the results are above the global value, which is 0.07 mSv y^{-1}, as stated by Unscear 2000 (4).

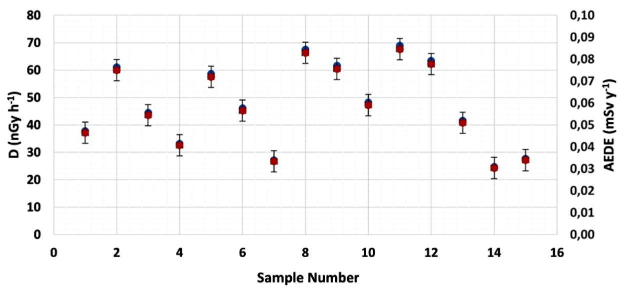

Figure 4. The combined graph of D and AEDE values in Bozcaada soils.

AGDE parameter values for soils were calculated between 0.180 and 0.490 mSv y^{-1}. The mean AGDE value was 0.337 mSv y^{-1} (table 4). The mean AGDE value for the Rize-Turkey Fırıtna Valley was determined by Kurnaz *et al.* (2007) who found it to

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be 0.551 mSv y^{-1} [22]. This result (0.551 mSv y^{-1}) is greater than the average AGDE value (0.337 mSv y^{-1}) calculated for Bozcaada soils. ELCR values for soils range from 0.106 × 10^{-3} to 0.296 × 10^{-3}. The mean ELCR was calculated as 0.204 × 10^{-3}. The values calculated for S8 and S11 soils have higher results than the Earth average value (0.29 × 10^{-3}) [4,19]. The calculated ELCR for other soils are below the world average.

Table 4. Results of radiological hazard parameters from soils in Bozcaada Island.

Sample No	Ra_{eq} (Bq kg^{-1})	D (nGy h^{-1})	AEDE (mSv y^{-1})	AGDE (mSv y^{-1})	ELCR ($x10^{-3}$)	Hin	H_{ex}
1	81.64	37.82	0.046	0.266	0.162	0.29	0.22
2	127.73	61.13	0.075	0.438	0.262	0.41	0.34
3	94.75	44.42	0.054	0.318	0.191	0.28	0.26
4	68.96	33.19	0.041	0.240	0.142	0.20	0.19
5	123.45	58.65	0.072	0.413	0.252	0.46	0.33
6	99.49	46.06	0.056	0.319	0.198	0.40	0.27
7	52.01	27.18	0.033	0.200	0.117	0.17	0.14
8	149.16	67.54	0.083	0.474	0.29	0.47	0.40
9	131.89	61.63	0.076	0.433	0.265	0.48	0.36
10	101.85	48.18	0.059	0.344	0.207	0.32	0.28
11	147.80	68.92	0.085	0.490	0.296	0.46	0.40
12	138.12	63.36	0.078	0.447	0.272	0.45	0.37
13	87.47	41.61	0.051	0.297	0.179	0.29	0.24
14	50.83	24.73	0.030	0.180	0.106	0.14	0.14
15	57.90	27.71	0.034	0.195	0.119	0.23	0.16
Mean ± SD	100.9± 34.3	47.5± 15.3	0.058± 0.02	0.337± 0.11	0.204± 0.07	0.34± 0.12	0.27± 0.09

Figure 5 shows the hazard indices (H_{in} and H_{ex}) for the soils in this study. H_{in} ranges from 0.14 to 0.48, while H_{ex} ranges from 0.14 to 0.40. The damage indices must be less than 1. The hazard indices calculated in this study are less than one.

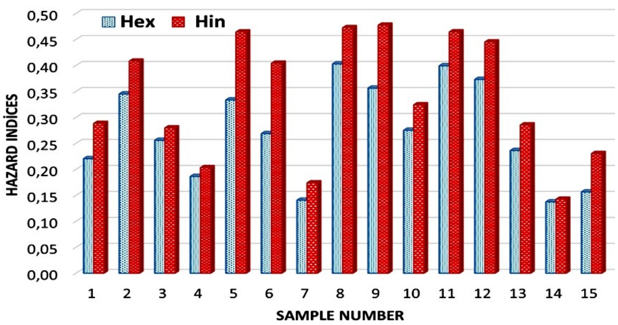

Figure 5. Internal and external damage indices (H_{in} and H_{ex}) calculated from Bozcaada soils.

DISCUSSION

Environmental pollution in the world and the increase in the activity of radionuclides that cause natural or artificial radiation in our environment are important factors affecting human health. Increased human exposure to environmental radiation may lead to an increased risk of cancer in humans. Bozcada is one of the Aegean islands that has gained importance in terms of tourism in recent years. Determining the activity level of 13^{137}Cs, ^{40}K, ^{238}U and ^{232}Th nuclides in the soil, which determine the environmental radiation of this island, is important for public health. The results of literature studies on soils and beach sands are given in tables 5 and 6, respectively.

When the average natural radionuclide levels in the soil of our study are compared with the results of studies conducted around the world and in Turkey, it is seen that our results are generally lower than the results of other studies, except for the studies in India, Iraq and Sakarya-Turkey (table 5). The mean potassium and mean thorium activities in our study exceed the world average values for ^{40}K and ^{232}Th, respectively. Due to the high potassium and thorium values of some soils (S2, S7, S8, S11 and S12 soil), high results were obtained in the absorption dose rate, AEDE and AGED values. 86% of the gamma dose exposure from the island soil comes from potassium (figure 3). This openly depends on the feature of the island's soil or whether the soil is used for farming purposes and the geological formation of the soil.

Table 5. Comparing the present study's soil results to those from other nations (Bq kg^{-1}).

Country	^{40}K	^{238}U	^{232}Th	References
Iraq	315.39	15.35	13.31	(5)
India	639.24	12.15	45.17	(8)
Bangladesh	475.51	15.39	28.35	(14)
Egypt	553.14	46.15	30.57	(23)
Saudi Arabia	212-915	1.4-35.3	2.5-39	(24)
Nigeria	1190.1	64.64	110.18	(25)
India	96.5	8.2	17.4	(26)
Saudi Arabian	790	23.8	24.33	(27)
Iraq	278.10	6.2	6.41	(28)
India	810.87	47.27	67.49	(29)
Türkiye-Karadağ Moun	451.1	71.6	83.9	(6)
Türkiye-Sakarya	371	23.2	21.0	(30)
Türkiye-Van	478.19	33.33	36.68	(31)
Türkiye-Kütahya	538.4	56.4	25.9	(32)
World average	400	35	30	(4)
Türkiye-Bozcaada	427	24	31	This study

The average values for potassium, uranium, and thorium activity determined for beach sands in our study are under the world mean value (table 6). The average potassium activity is lower than most of the literature studies. The average uranium activity has similar results to other studies except for those done in Greece and Çanakkale-Turkey. The average thorium activity is lower than the results of the other literature, except for the study conducted in Kocaeli-Turkey. Unfortunately, it is seen in table 6 that the average cesium activity calculated for beach sands is higher than the literature studies. Cesium is an artificial radionuclide and emits gamma rays of 662Kev. Measuring cesium in beach sands provides a measure of the cesium released into our environment because of nuclear accidents. This is important as a condition that affects human health.

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Table 6. Average radionuclide activities in beach sands reported for Türkiye and the world (Bq kg^{-1}).

Country	^{40}K	^{238}U	^{232}Th	^{137}Cs	References
Iranian	337.5	19.2	17.9	3.35	(20)
Saudi Arabia	392	22.7	14.8	1.38	(21)
Pakistan	287	22	36	~1.2	(33)
Greece	782.8	47.2	50.8	–	(34)
China	401.0	14.1	11.3	–	(35)
Türkiye-Mediterranean	157.7	12.2	9	0.4	(15)
Türkiye-Çanakkale	1160.7	290.4	532	2.3	(36)
Türkiye-Kocaeli	219.4	8.85	8.93	2.59	(37)
World average	400	35	30	–	(4)
Türkiye-Bozcaada	329	23	11	14	This study

The results of radiological hazard parameters in the literature are given in table 7. While our results are higher than the results of studies conducted in India, Saudi Arabia, Nigeria, Iraq and Turkey, they are also lower than the results of studies conducted in Egypt, Saudi Arabia, India and the world average limit values (table 7). Although most radiological hazard values calculated for Bozcada soils are below the limit values, there are also risks for high values. For this reason, it is important to carry out more studies to protect the health of the people living in Bozcada's points where high values are measured. When the correlation test was performed with all data obtained from soil samples, it was observed that there was a positive correlation ($p < 0.01$) between thorium activity and radiological hazard indices.

Table 7. Radiological parameters calculated for soils in different studies around the world.

Country	Ra_{eq} (Bq.kg^{-1})	D (nGy h^{-1})	AEDE (mSv y^{-1})	AGDE (mSv y^{-1})	ELCR (x10^{-3})	Refer-ences
India	40.5	18.3	0.022	0.128	0.783	(16)
Egypt	144.8	67.4	0.08	0.47	-	(23)
Saudi Arabian	68.1	35.2	0.37	-	0.2	(24)
Nigeria	64.64	144.93	0.18	1.026	0.62	(25)
Saudi Arabian	117.1	58.88	0.07	-	-	(27)
Iraq	36.79	18.33	0.022	-	0.078	(28)
India	206.21	94.4	0.116	-	0.352	(29)
Türkiye-Sakarya	64.14	30.93	0.038	-	-	(30)
Türkiye-Van	-	57.5	0.071	-	-	(31)
Türkiye-Bolu	62.8	29.9	0.037	0.21	1.3	(38)
World average	370	60	0.07	0.3	0.29	(4)
Türkiye-Bozcaada	100.9	47.5	0.058	0.337	0.204	This study

CONCLUSION

With this study, it was determined that the natural radioactivity levels of Bozcaada Island beach sands were lower than the natural radioactivity levels of the island soils. Since Bozcada is an island that attracts tourists, the low radionuclide activity in the beach sands shows that this place does not pose a significant radiological threat to humans.

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