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Assessment of natural radioactivity levels for Karadağ Mountain, Turkey

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► ***Original article***

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ABSTRACT

Background:The natural radioactivity levels in soil samples of Karadağ Mountain in central Anatolia region have been determined. ***Materials and Methods:*** Analyses on the collected samples were performed to determine gross alpha and beta radioactivity concentrations by using a gas-flow proportional counter and the concentrations of ^{238}U, ^{232}Th and ^{40}K by using a NaI(Tl) scintillation detector. ***Results:*** The estimated activities of gross alpha and beta ranged between 305.155±46.830 and 1305.437±77.23 Bq.kg-1, 479.743±22.658 and 1177.373±30.908 Bq.kg-1, respectively. The mean activity values of U, Th and K radionuclides were found to be 71.6, 83.9 and 451.1 Bq.kg-1, respectively. Also, known radiation health hazard indices were calculated using radioactivity concentrations of soil samples. ***Conclusion:*** The present results have been compared with the obtained values from other regions in Turkey and the internationally reported values as well as the reference values. The soil samples in the studied area are safe and can be used as a construction material without posing any significant radiological threat to public. This investigation reveals a baseline of levels of natural radioactivity in Karadağ Mountain, Turkey.

Keywords: *Karadağ mountain, natural radioactivity, gross alpha/beta, NaI(Tl) detector.*

INTRODUCTION

There is the natural radioactivity since the creation of the earth and radionuclides are found naturally in water, soil and air. Exposure to ionizing radiation is caused by naturally occurring sources such as from both outer space and radon gas emanating from rocks in the Earth and sources with an artificial origin such as unplanned events [1]. Human beings are always exposed to ionizing radiations emitted from naturally occurring radioactive ^{238}U series, ^{232}Th and radioactive ^{40}K. The mentioned radioactive nuclides are widely spread in the environment of earth and it is present in various forms whose abundances differ significantly depending on the geographical and geological features in any area [2].

Determination of the activity concentrations of natural radioactive nuclides in soils gives knowledge of the natural sources. Since these radionuclides are not uniformly distributed, information on their distribution in a region plays an important role in radiation measurement and protection [3–6].

The objective of this work is to focus on assessing the levels of gross alpha and beta, natural radioactivity and dose in soil samples collected from 25 different locations of Karadağ Mountain, Turkey. This paper is important in two reasons: Firstly, to the best of our knowledge, there has been no information available about gross alpha, gross beta and gamma radiation levels of the soil samples we present in this paper. Secondly, this region is approximately 175 km close to Akkuyu Nuclear Power Plant (NPP) which will be operated at Mersin Province, Turkey. Since there has been no available information regarding the radioactivity levels of the soil samples of the

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reactor site, this work will be important contributions to the literature.

Study Area

Karadağ Mountain, which is an extinct volcano in Karaman Province Turkey, is located at the latitude of 37.25°N and the longitude of 33.08°E. It's between the Mediterranean region and the central Anatolia region of Turkey (figure 1). It is about 25 km north of Karaman. The peak of the mountain is 2.25 km east of this plain and its altitude is 2271 m.

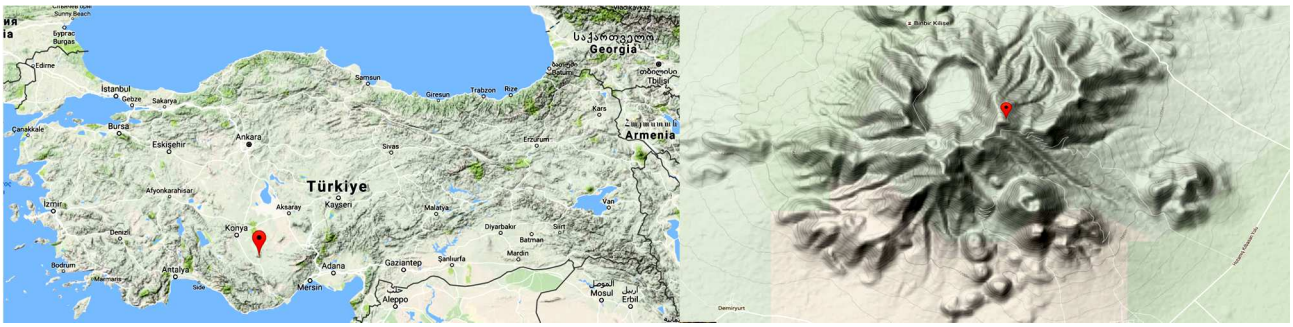

Figure 1. A map of Karadağ Mountain, Turkey (study area).

MATERIALS AND METHODS

Gross alpha and beta radioactivity

About 100 mg of dry soil was weighed in stainless steel planchets. The sample was spread in a planchet until it was homogeneous. A drop of distilled water was spread at the sample's surface and it was later evaporated under IR lamps. Then, the samples were dried in an oven at about 105 °C for 90 mins. Activities of gross alpha and beta were estimated exploiting a gas-flow proportional counter. The counting gas (P-10) was a mixture of 10% methane and 90% argon. The background value of each detector was obtained by counting an empty planchet for 900 mins. The counting time was set as 900 mins for both gross alpha and beta activities. Alpha and beta efficiencies of counting system were checked with ^{90}Sr and ^{241}Am sources, respectively.

Gamma spectrometry measurements

The twenty five surface soil samples were collected from uncultivated locations at about 1 km intervals along the Karadağ Mountain area. At each location, the ground was cleared of pebbles, roots, stones and vegetation, then 2 kg of material from the first 30 cm of top soil was placed in a labeled plastic container. The samples were transferred to the laboratory where they were first dried in air at room temperature for 10 days and then ground into fine powder to pass through a screen. The homogenized samples were sealed in 100 ml beakers, dry-weighed and stored for about 30 days in order to provide radioactive equilibrium between ^{226}Ra and its daughters.

Gamma spectrometry measurements were performed utilizing a 3" x 3" NaI(Tl) scintillation detector. The detector was surrounded by a height of 38 cm thickness and a special cylindrical lead shield of about 10 cm to decrease the background. All the selected samples were subjected to gamma spectral analysis with a counting time of 105 s. Efficiency calibration of the system in the energy range of 186.2–2614.4 keV was done using the well-known reference materials of IAEA: RGK-1, RGU-1 and RGTh-1. The radionuclides in these soil samples were identified an energy peak at 1460 keV for ^{40}K, the activity of ^{238}U from the 1764 keV gamma line of ^{214}Bi and that of ^{232}Th from 2620 keV gamma line of ^{208}Tl.

RESULTS AND DISCUSSION

Measurement of gross alpha and beta

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radioactivity

The activity of the samples can be calculated as follows using Equation (1):

$$A_{\alpha,\beta} = \frac{N}{m * Eff * A_f * 60} \quad (1)$$

Where N_{et} is the net count under the spectrum for alpha and beta, respectively, m is the sample mass, A_f attenuation factor, Eff is the efficiency of the counter to alpha and beta, respectively [4].

As it can be seen in table 1, the measured activity concentrations of gross alpha varied from 305.155±46.830 Bq·kg^{-1} to 1305.437±77.23 Bq·kg^{-1} with an average of 733.76. Gross beta activity concentrations ranged between 479.743±22.658 Bq·kg^{-1} and 1177.373±30.908 Bq·kg^{-1} with an average of 867.06.

The activity values of gross alpha and beta were comparable to previous studies shown in table 2. It was observed that gross alpha and beta radioactivity concentrations in soil samples were relatively lower than those in Malaysia [7] and Turkey (Van) [8] but higher than Serbia [9], Republic of Srpska [10] and Turkey (Marmara)[11].

Gamma spectrometric analysis

The measured activity concentrations of natural occurring radionuclides namely ^{238}U, ^{232}Th and ^{40}K in soil samples collected from the 25 different locations of Karadağ Mountain were determined by gamma ray spectrometry. In Table 3, the results of the activity concentrations of these radionuclides were demonstrated.

Table 1. Measured activity levels ± standard errors of gross alpha and gross beta in soil samples.

Sample	Residue (mg)	Gross Alpha (Bq.kg^{-1})	Gross Beta (Bq.kg^{-1})
S1	97.5	525.749 ±50.225	944.581±29.868
S2	96.7	408.214 ±49.098	479.743±22.658
S3	102.7	538.982 ±54.806	643.614±24.722
S4	109.6	552.638 ±54.463	900.026±27.695
S5	107.9	662.742 ±56.186	938.978±28.399
S6	92.9	667.334 ±55.948	643.410±25.917
S7	116.2	943.179 ±69.151	1065.076±29.221
S8	110.1	1083.555 ±68.574	977.688±29.031
S9	105.1	546.019 ±52.34	1065.418±30.422
S10	109.5	1142.420 ±72.162	1025.593±29.349
S11	111.6	1192.452 ±73.910	1134.276±30.849
S12	108.5	601.749 ±55.577	930.514±28.288
S13	96.4	622.981 ±52.192	791.391±27.985
S14	116	877.324 ±66.738	955.570±27.388
S15	115.9	1305.437 ±77.23	1177.373±30.908
S16	123.7	751.609 ±63.549	885.750±25.984
S17	116.7	613.763 ±56.529	894.461±26.686
S18	121.2	1125.722 ±74.918	757.092±24.214
S19	117.7	596.199 ±59.475	646.000±22.914
S20	105.7	421.857 ±49.294	728.164±25.627
S21	114.6	305.155 ±46.830	743.093 ±24.636
S22	108.4	702.766 ±59.854	717.702 ±24.768
S23	111.8	575.779 ±57.228	732.331±24.774
S24	107.5	941.540 ±63.994	1046.293 ±30.158
S25	106.7	638.885 ±54.726	852.453 ±27.337

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Table 2. Comparison of gross alpha and beta activities (Bq.kg-1) among Karadağ Mountain and previous works.

Region	Gross Alpha	Gross Beta	Reference
Maan (Jordan)	3.17 – 29.25	634 – 1084	[4]
Muar (Malaysia)	<MDA – 2291	128 – 1419	[7]
Van (Turkey)	686 – 4713	73 – 9524	[8]
Obrenovac (Serbia)	–	93 – 262	[9]
Drazljevo (Republic of Srpska)	66.7 – 102.4	285.7 – 607.4	[10]
Marmara (Turkey)	–	500 – 830	[11]
Aladja, Ovwian, DSc Township and Warri (Nigeria)	32 – 64	411.5 – 2710	[12]
Rize (Turkey)	100.72 – 932.57	171.35 – 1269.01	[13]
Karadağ Mountain (Turkey)	305 – 1305	479 – 1177	This study

MDA: Minimum Detectable Activity

Table 3. Activity concentrations ± standard errors of 238U, 232Th and 40K for soil samples (Bq.kg-1) in Karadağ Mountain.

Sample	^{238}U	^{232}Th	^{40}K
S1	102.8±16.3	25.9±90.2	104.6±542.8
S2	17.7±43.7	29.2±107.7	113.3±417.0
S3	16.9±51.2	25.9±84.5	315.7108.1
S4	13.0±35.6	25.8±120.9	106.0±468.5
S5	15.6±94.0	24.4±117.9	100.6±447.1
S6	16.6±47.7	26.2±123.7	106.6±250.1
S7	16.4±43.5	25.6±104.6	104.6±478.5
S8	16.2±96.5	25.8±58.9	105.6±353.6
S9	14.3±135.1	21.2±77.6	89.7±543.5
S10	14.0±73.3	21.4±56.9	90.0±539.7
S11	14.0±96.7	21.3±49.5	87.5±482.5
S12	17.9±48.1	27.8±92.2	112.8±580.7
S13	15.3±85.1	24.0±40.4	98.3±328.2
S14	17.4±76.9	27.6±58.6	110.9±591.4
S15	16.9±72.8	25.8±89.4	106.6±651.2
S16	16.0±71.3	24.9±96.5	102.2±430.1
S17	18.6±32.7	29.4±73.5	119.3±472.4
S18	16.6±66.8	26.9±58.8	104.9±305.2
S19	20.2±58.6	30.7±140.6	126.6±452.8
S20	19.1±56.6	31.5±85.7	122.7±472.2
S21	17.5±87.2	27.3±57.9	112.5±503.2
S22	16.5±81.6	26.6±87.1	106.0±393.6
S23	13.2±76.9	21.0±66.1	82.8±456.5
S24	16.1±72.8	25.1±70.0	103.4±355.5
S25	14.5±82.6	22.3±88.1	92.3±446.0
Range	135.1–32.7	140.6–49.5	651.2–250.1

The activity concentrations range for ^{238}U, ^{232}Th and ^{40}K are 32.7±13.0 (S17) –135.1±14.3 (S9) Bq.kg^{-1} with an average of 71.6 Bq.kg^{-1}, 49.5±21.3 (S11) –140.6±30.7 (S19) Bq.kg^{-1} with an average of 83.9 Bq.kg^{-1} and 250.1±106.6 (S6) – 651.2±106.6 (S15) Bq.kg^{-1} with an average of 451.1 Bq.kg^{-1}, respectively.

The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples collected from this study area are higher than the worldwide

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average concentrations of the above-mentioned radionuclides reported by UNSCEAR [2] as 35, 30 and 400 Bq.kg^{-1}, respectively. The comparison of average activity concentrations with the different parts of Turkey such as Tekirdag [14], Kastamonu [15], Buyukeceli [16], Cankiri [17], Karaman [18], Fırtına Valley [19]), Manisa [20], Çanakkale [21], Erzincan [22] and Rize [23] is shown in table 4.

Table 4. Comparison of activity concentration of natural radioactivity levels (Bq.kg-1) in soil samples from different parts of Turkey.

Region	^{238}U	^{232}Th	^{40}K	Studies
Tekirdag	97.89–6.78	112.6–17.24	1466–195.7	[14]
Kastamonu	49.79–26.80	35.62–17.06	868.77–155.7	[15]
Büyükeceli	258.6–9.8	87.6–11.7	1949.5–174.8	[16]
Cankiri	52–5	95–7	752–111	[17]
Karaman	46–15.5	39.5–12.6	566.3–140	[18]
Fırtına Valley	188–11	105–10	1235–105	[19]
Manisa	35–22	36–18	470–210	[20]
Çanakkale	253.1–21.39	160.9–38.84	3307–83.1	[21]
Erzincan	23 – 1	29.4 – 1.2	977.8 – 64.7	[22]
Rize	-	125.53 – 19.58	1159.51 – 302.40	[23]
Karadağ	135.1–32.7	140.6–49.5	651.2–250.1	This study
World	35	30	400	[2]

To evaluate a characteristic of the external terrestrial gamma radiation, the absorbed dose rate (D) in air at 1m above the ground surface owing to the concentration of radionuclides was calculated by the following Equation (2) [2,24]:

$$D = 0.462\,.A_U + 0.623\,.A_{Th} + 0.0417\,.A_K \qquad (2)$$

where A_U, A_{Th} and A_K are the activity concentrations (in Bq.kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in soil samples, respectively. The absorbed dose rate ranged between 77.94 and 135.29 nGyh^{-1} with an average value of 103.95 nGyh^{-1} as shown in table 5. In the report of the UNSCEAR [2], it is seen that the level of this gamma dose rate in the world is in the range of 10–200 nGy/h.

The concentration and distribution of natural occurring radionuclides for the soil samples under investigation are not uniform. Therefore, the radium equivalent activity (Raeq) which is the common radiological index was the most widely used to determine the actual activity levels of ^{238}U, ^{232}Th and ^{40}K in the soil samples and the radiation hazards associated with these radionuclides. Under the assumption that 370 Bq.kg^{-1} of ^{226}Ra or 260 Bq.kg^{-1} of ^{232}Th or 4810 Bq.kg^{-1} of ^{40}K produce the same gamma dose rate, this quantity is defined by Equation (3) [25,26]:

$$Ra_{eq} = A_U + 1.43\,A_{Th} + 0.077\,A_K \qquad (3)$$

Where A_U, A_{Th} and A_K are the activity concentrations (Bq·kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in investigated samples, respectively. The calculated values of radium equivalent activity for the cited radionuclides in soil samples under investigation varied from 174.07 to 296.82 Bq.kg^{-1} as given in table 5. It is found that Raeq is lower than the maximal admissible limit of 370 Bq.kg^{-1} proposed by the Organization for Economic Cooperation and Development [27].

In order to estimate the annual effective dose (AED) rates, the conversion coefficient from absorbed dose in air to effective dose rates and the outdoor occupancy factor recommended by UNSCEAR [2] were used. Thus, the AED can be given by Equation (4) [2,28]:

$$AED = D \times DCF \times OF \times T \qquad (4)$$

Where D is the absorbed dose rate, DCF is dose conversion factor (0.7 SvGy^{-1}), OF is outdoor occupancy factor (0.2) and T is described as time factor. In present work, this

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rate varied from 95.58 Sv yr^{-1} to 165.93 μSv yr^{-1} with an average value of 127.48 Sv.yr^{-1} which is rather lower than the world average AED from outdoor terrestrial gamma radiation which is 460 μSv.yr^{-1} (table 5).

Table 5. Absorbed dose rate, radium equivalent activity, annual effective dose and external hazard index ± standard errors of soil samples.

Sample	ADR (nGy/h)	REA (Bq/kg)	EHI	A E D (micSv/year)
S1	104.51±26.57	273.36±80.12	0.74±0.02	154.57±43.52
S2	89.34±31.55	229.63±108.08	0.62±0.02	128.17±50.12
S3	89.34±30.10	196.25±84.14	0.53±0.01	109.57±40.88
S4	111.07±33.64	244.22±100.28	0.66±0.02	136.22±45.68
S5	135.29±27.57	296.82±73.60	0.80±0.01	165.93±37.44
S6	109.40±32.99	243.64±99.17	0.66±0.02	134.17±44.81
S7	104.99±34.05	229.66±99.72	0.62±0.02	128.77±46.25
S8	95.85±35.37	207.90±85.55	0.56±0.02	117.55±48.04
S9	133.17±30.54	287.87±73.55	0.78±0.01	163.32±41.47
S10	91.58±29.84	196.10±72.80	0.53±0.01	112.32±40.53
S11	95.42±33.85	204.58±79.88	0.55±0.02	117.02±45.98
S12	103.65±36.21	224.47±101.63	0.61±0.02	127.12±49.19
S13	77.94±38.05	167.95±89.84	0.45±0.02	95.58±51.67
S14	96.46±38.98	206.14±94.28	0.56±0.02	118.30±52.95
S15	116.21±32.41	250.58±84.69	0.68±0.01	142.51±44.02
S16	110.80±28.71	242.26±77.14	0.65±0.01	135.89±39.00
S17	80.44±40.39	174.07±115.71	0.47±0.02	98.65±54.85
S18	80.06±32.37	174.27±81.18	0.47±0.02	98.19±43.96
S19	133.30±39.46	294.18±116.94	0.80±0.02	163.48±53.60
S20	99.00±36.99	215.27±99.59	0.58±0.02	121.41±50.24
S21	97.12±38.73	208.65±93.22	0.56±0.02	119.10±52.61
S22	108.19±30.22	236.34±78.26	0.64±0.01	132.69±41.04
S23	95.52±26.59	206.43±66.01	0.56±0.01	117.15±36.12
S24	91.90±29.96	200.18±76.40	0.54±0.01	112.71±40.69
S25	111.39±26.37	242.67±68.29	0.66±0.01	136.61±35.81

Another index to provide radiological suitability of naturally occurring radioactive nuclides is the external radiation hazard (*Hex*). This hazard parameter is calculated by Equation (5) given as [25,29]:

$$H_{ex} = A_U/370 + A_{Th}/259 + A_K/4810 \quad (5)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations (in Bq·kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in soil samples, respectively. The maximum value of external (H_{ex}) radiation hazard index should be less than unity. The value of this parameter was obtained from the measured activity concentrations of ^{238}U, ^{232}Th and ^{40}K for the soil samples under investigation. As shown in Table 5, the corresponding external hazard index varied from 0.47 (S17) to 0.80 (S5) with the mean values of 0.61. These results are less than unity for the radiation hazard to be negligible.

The corresponding frequency distributions of the activities for above-mentioned radionuclides are shown in figure 2. It can be observed that the positive values of skewness calculated for ^{238}U (0.484) and ^{232}Th (0.388) activity concentrations represent that their distribution are asymmetric with the left tail being shorter than the right. Nevertheless, the negative value

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obtained for skewness coefficient of ^{40}K (–0.109) indicates that this distribution is symmetric with the left tail being longer than the right as illustrated in figure 2.

As a result of the one–way ANOVA analysis in accordance with the 5% importance level, there is a significance difference ($p < 0.05$) among concentrations of ^{238}U, ^{232}Th and ^{40}K. The relationships among the cited radionuclides were determined with help of the Pearson's correlation coefficients. The strong interaction was found between ^{238}U and ^{40}K concentrations ($p<0.01$), whereas there was a negative correlation and a significant difference at 95% confidence interval between ^{232}Th and ^{238}U and between ^{232}Th and ^{40}K activity concentrations.

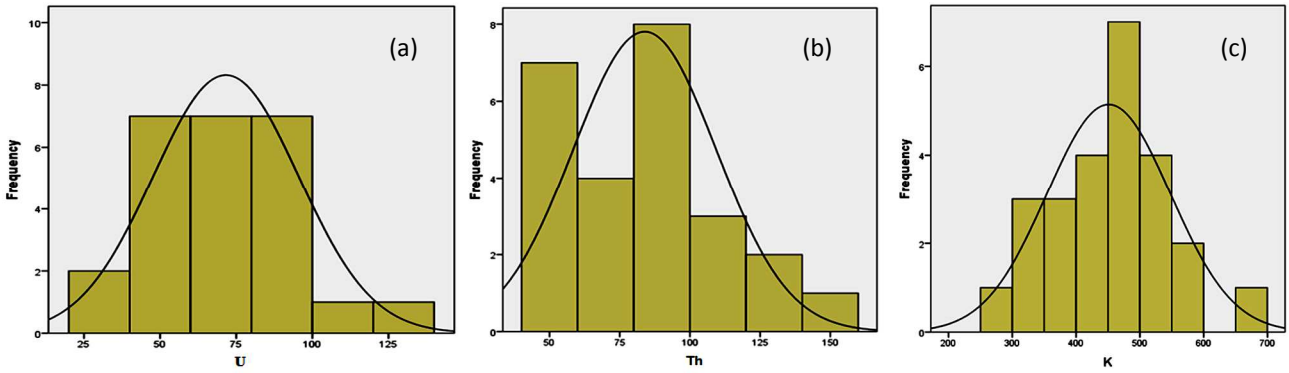

Figure 2. The frequency distribution of the activity of (a) ^{238}U, (b) ^{232}Th and (c) ^{40}K.

CONCLUSION

According to data resulting from this work, soils of the region studied here are safe and can be used as a construction material without posing any significant radiological threat to people. Therefore, it can conclude that this area has no significant health threat. The values resulting from this work can be used for comparison in future works and can be useful for preparing a radiological map of the region. The results can be also used as reference data for monitoring possible radioactivity pollutions in future after operating a NPP in this region.

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Conflicts of interest*: *Declared none.

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