Radioactivity level and the measurement of soil gas radon concentration in Dikili geothermal area, Turkey

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ABSTRACT

Background: The natural radioactivity level and the radon concentration of soil were measured at four important geothermal area located in Dikili geothermal region, Turkey. ***Materials and Methods***: The natural radionuclide content of soil samples were measured by NaI(Tl) gamma spectrometer system and the soil radon concentration were determined using Kodak-Pethe LR-115 Type II Solid State Nuclear Track Detectors (SSNTD). The aim of the study was to investigate the seasonal variation of the radon concentration as well as evaluate the health hazards related to natural activity if any. ***Results***: It was found that the radon concentration of soil gas in the study area ranged from 98-8594 Bq m^{-3} with an average value of 1920 Bq m^{-3}**.** The highest radon concentration observed in summer and the lowest concentration measured in winter. The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K were found to be 28.7, 17.6 and 579.2 Bq kg^{-1}, respectively. Towards this, annual effective doses from these radionuclides determined and analyzed. ***Conclusion***: The calculated dose values are not very high and don't exceed the radioprotection standards suggested by international agencies.

Keywords: *Radon, soil, natural radioactivity, Dikili, Turkey.*

INTRODUCTION

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust present in soil, air, water, food and the body (1).

Radiation coming from space can be classified according to origin as trapped particle radiation, galactic and solar radiation. Trapped radiation consists mainly of electrons and protons held in orbits around the earth by its magnetic field. Galactic cosmic radiation are created outside the solar system, they are generally believed to be produced and accelerated as a consequence of stellar flares, supernova explosions, pulsar acceleration or the explosion of galactic nucleon. Solar radiation, as the name implies, comes from the sun (2).

Naturally occurring radionuclides of terrestrial origin arises mainly from the primordial radionuclides that have long half-lives comparable with the age of the earth. These primordial radionuclides are ^{238}U, ^{232}Th and their decay products as well as the radioisotopes of ^{40}K (3,4). The specific levels of these radionuclides are related to the types of rock from which the soils originate. Therefore, terrestrial radiation appears at different levels in the soil of each region in the world. The higher radiation levels are associated with igneous rocks, such as granite, while the lower levels relate to sedimentary rocks. On the other hand there are expectations such as some areas consist of certain shale's or phosphate rocks which have relatively high content of radionuclides. Many surveys have been conducted to determine the background levels of radionuclides in soils, which can in turn be related to the absorbed dose rates in air. The latter can easily be measured directly, and these results provide an even more extensive evaluation of the background exposure levels in different countries. All of these spectrometric measurements indicate that the three components of the external radiation field, namely from the gamma-emitting radionuclides in the ^{238}U and ^{232}Th series and ^{40}K, make approximately equal contributions to the externally incident gamma radiation dose to individuals in typical situations both outdoors and indoors [(1)].

Radon (^{222}Rn), which is the member of ^{238}U decay series, is of special interest since Radon and its non-gaseous short-lived daughters namely, ^{218}Po and ^{214}Po are the most important radioactivity sources in air and they cause about half of the effective dose equivalent of all natural ionizing radiations [(5)]. The radon and its progeny enter into human's body mainly through ingestion and inhalation [(6)]. Exposure of person to high concentration of radon and its short-lived progeny for a long period leads to health problems, particularly lung cancer [(1, 7)].

It is well known that active geothermal areas contain much higher radon in soil compared to a relatively passive area [(8)]. The existence of geothermal spring in an area indicates the fracture zones. Such regions having many active faults are generally highly permeable. Therefore, the active faults are significant pathways for radon and other terrestrial gasses to leak from the crust [(9)]. Most of the ^{222}Rn surveys in geothermal fields reported in the literature consist of measurements of radon concentration in springs or soil [(10-14)]. An investigation realized in India showed that the radon content of soil around the thermal springs is very high (1657-1855 Bqm^{-3}) and the soil exhalation rates vary between 831 and 4550 $(mBqm^{2}h)^{-1}$ [(13)].

It is important to assess the radiation doses taken by human from natural sources because the largest contribution to the collective effective dose received by the world's population come from the natural radiation [(2)]. Over the past several years, investigations on terrestrial radiation and especially on radon have received particular attention worldwide and also led to extensive surveys in Turkey. Terrestrial radioactivity levels and radon concentrations of various locations in Turkey have been reported in some studies [(15-30)].

The aim of the study was to investigate the seasonal variation of the radon concentration levels in soil, determine natural radioactivity concentrations in soil samples as well as evaluate the health hazards related to natural activity if any in Dikili Geothermal Region. In view of this, the annual effective dose from outdoor terrestrial radiation was calculated for assessment of radiation exposures to the population. The results were also compared with national and world averages.

MATERIALS AND METHODS

Geological settings of the research area

Dikili geothermal area lie on Bergama Graben System located in Northwest of İzmir. Zeytindali, Nebiler, Camur and Bademli which constitute the Dikili geothermal area was selected as study sites (figure 1).

In the area there are three kinds of faults NW-SE, NE-SW and WNW-ESE. Also there are many thermal springs whose distribution is controlled by fracture patterns [(31)]. NE–SW extensional horst-graben systems characterize the structure of the region [(32)]. The area has complex magmatic and volcanic geological structures and numerous graben-horst systems [(33-36)]. A large part of the investigation area is covered with volcanic material, known as Yunt-dağ volcanic [(31)] and some residual rock formations cover a small part of the area in the east. The Yuntdağ volcanics were divided into three groups: Yuntdağ volcanic-I (Tyu1), Yuntdağ volcanic-II (Tyu2) and Yuntdağ volcanic

-III (Tyu3). The oldest Yuntdağ volcanic-I consists of widely altered andesite. Tertiary Demirtaş pyroclastics mainly made up of felsic pyroclastics cover the Yuntdağ volcanic-I. Overlying Yuntdağ volcanic- II is restricted to the western of the study area. The rock consists of dark compact basalt and pyroxene andesite lava. In the rocks, a few small hydrothermal veins are found. This unit is covered with the youngest Yuntdağ volcanic-III. The rock that consists of biotite, hornblende and andesite is dome shaped volcano type (32).

Radon Measurements in Soil

Solid state nuclear track detectors (SSNTD) are becoming very popular tool for the radon measurements in soil. LR-115 has several characteristics: (1) very sensitive to alpha particles only; (2) can be used for short-term measurement at minimum 10–30 days of exposure and also for long-term measurement, 3 months up to 1 year; (3) insensitive to environmental changes such as humidity, water and temperature up to 60 ˚C; (4) suitable to use for radon measurements in stagnant or flowing water (38). The principle of radon detection of solid state nuclear track detectors are based on counter of alpha particle (when radon decays to Po alpha particles are emitted) tracks producing on solid state materials (39).

Nuclear track detectors are basically electrical insulating solid materials including minerals, crystals and plastics. The passage of heavily charged particles in these materials creates damage zones along of their paths on an atomic scale called latent tracks. Since the tracks are very thin (thickness a few hundred Angstroms) an optical microscope cannot be used for their analyses. Only using chemical or electrochemical etching allows their visualization under optical microscopes (40). In chemical etching usually NaOH or KOH solutions is used (39).

In this study, Kodak-Pethe LR 115 Type II detectors (Dosirad, France) was used for measuring ^{222}Rn concentration in soil. LR-115 detectors of dimension 1.5 cm×1.5 cm placed inside plastic cups (one of its size is open). The cups (includes 3 detectors) were placed inside the pits excavated to a depth of 50 cm from the surface. The soil gas radon concentration measurements started on November 2008. Since

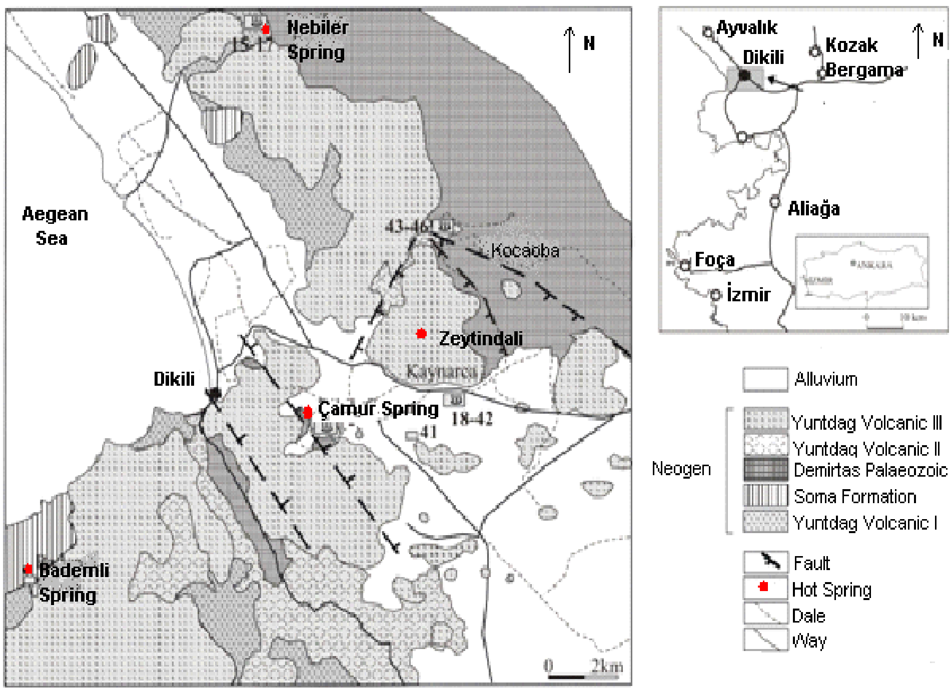

Figure 1 Geological map of the study area (37).

then detectors are collected and replaced by new ones each 3-5 weeks. The etching processes of the LR-115 detectors were carried out in an incubator including 10 % NaOH solution maintained at 60 ^{0}C for 120 minutes and then detectors were stand in distilled water for 20 minutes. Tracks on the detectors were counted under a digital microscope (41).

The detectors calibrated with a radium standard in TAEK-CNAEM and the calibration factor found to be 0.137kBqhm-3/trackcm-2.

^{238}U, ^{232}Th and ^{40}K Analyses in Soil

Soil samples were collected from the soil surface and transported to laboratory. The soil samples were air dried for 2–3 day, pulverized, homogenized and sieved through 2 mm mesh. About 100 g of the meshed soil samples were filled in 100 ml breakers. The breakers were then sealed and stored for at least 40 day to allow radioactive equilibrium between Radon and its decay products. Measurements of natural radionuclides, namely ^{238}U, ^{232}Th and ^{40}K in soil samples were undertaken by using a NaI(Tl) gamma scintillation detector (Tennelec 3"×3") coupled to a Canberra AMP/TSCA (Model 2015A) Amplifier, Canberra Multiport II and Genie 2000 spectroscopy software. The detector was enclosed in a 7.5 cm thin lead shield to protect the measurement from the background gamma radiation. The activity determination was based on 1.76 MeV gamma rays from ^{214}Bi for ^{238}U, 2.62 MeV gamma rays from ^{208}Tl for ^{232}Th. The activity of ^{40}K was determined through its 1.46 MeV gamma rays.

RESULTS AND DISCUSSION

The study was undertaken at four geothermal areas (Zeytindali, Nebiler, Camur, Bademli) to gather data for ^{238}U, ^{232}Th, ^{40}K and ^{222}Rn in soils of Dikili Geothermal Region during the period from November 2008 to November 2009.

Radon in soil

The radon levels (periodic and average) in soil air of the four geothermal areas at a depth of 50 cm are represented in figure 2. The average radon concentration in soil of Zeytindali, Nebiler, Camur and Bademli was 1137, 2795, 2986 and 2360 Bq m^{-3} respectively. The radon concentration in soil gas around Dikili was found to vary from 299 Bq m^{-3} to 2412 Bq m^{-3} at

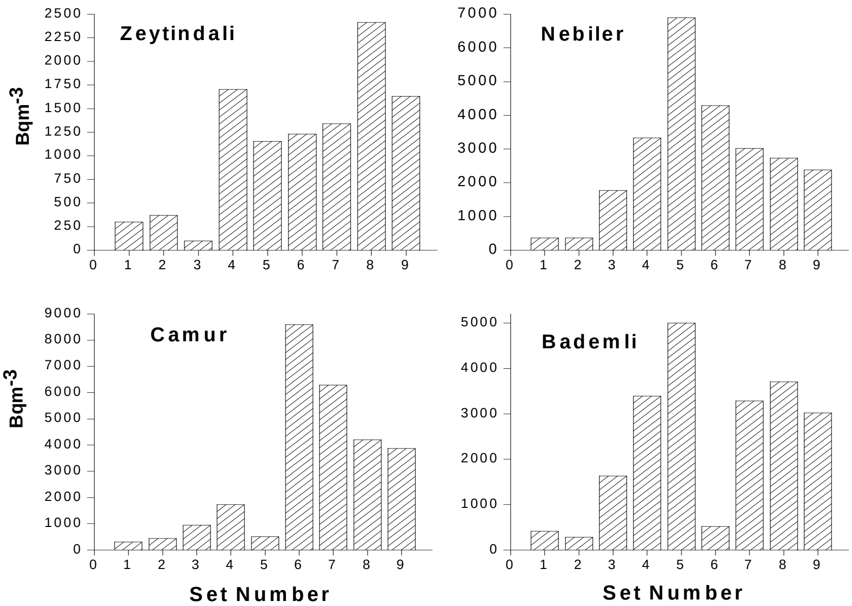

Figure 2. Outdoor radon concentrations in the four geothermal areas located in Dikili Geothermal region Set numbers (1 [15 November 2008-2 December 2008]; 2 [2 December 2008-13 January 2009]; 3 [13 January 2009-25 February 2009]; 4 [25 February 2009- 30 March 2009]; 5 [30 March 2009-17 May 2009]; 6 [17 May 2009-18 June 2009]; 7 [18 June 2009-28 July 2009]; 8 [28 July 2009-8 September 2009]; 9 [8 September 2009-30 November 2009]).

Zeytindali, 364 Bq m^{-3} to 6900 Bq m^{-3} at Nebiler, 299 Bqm^{-3} to 8594 Bq m^{-3} at Camur and 283 Bq m^{-3} to 4996 Bq m^{-3} at Bademli. Other similar measurements performed by various researchers showed that the soil gas radon concentration may vary over a wide range depending on weather conditions, climatic factors and soil type [42]. Also the radon-variation patterns changed with time, possibly because of disturbance of site condition by fault movement.

The highest level (8594 Bq m^{-3}) was observed in Camur in summer season and the lowest (98 Bq m^{-3}) was in Zeytindali in winter. One reason for these can be the seasonal changes of radon concentration. Such picture peculiar for all investigated stations, in other word, the measured soil gas radon concentrations in winter were lower than those measured in summer. This is because, in winter months, the soil is wet, humid and of lower porosity that may decrease diffusion of radon gas. However, in spring and summer months, the humidity of the soil is lower than that of winter, so the radon concentration increases due to the increase of porosity. Whereas in autumn, the humidity begin to increase and also porosity of soil decrease again, so the radon diffusion flow is getting lower [43].

Also these results are in good accordance to findings observed by King who pointed out that during the rainy winter seasons, radon tended to be confined underground by the water-saturated surface soil which had much reduced gas permeability, while during the sunny summer seasons, it exhaled more readily as the soil became drier and more permeable [44].

Figure 3 shows the frequency distribution of radon concentration in soil gas in Dikili Geothermal Region.

A comparison of measured radon concentrations in soil gas with the results of different studies carried out around the world and Turkey was given in table 1.

As can be seen from table 1 that the radon values in soil gas in the study area are lower than those reported in different studies around the world, thus seem to be safe from the health aspects. Besides, the obtained values in this study are below the action levels recommended by different agencies such as USEPA, UNSCEAR, and ICRP [1, 45, 46]. It is apparent from table 1 that our measurements are consistent with radon concentration measurements in the soil gas measured along many active faults in other studies in Turkey [15, 47].

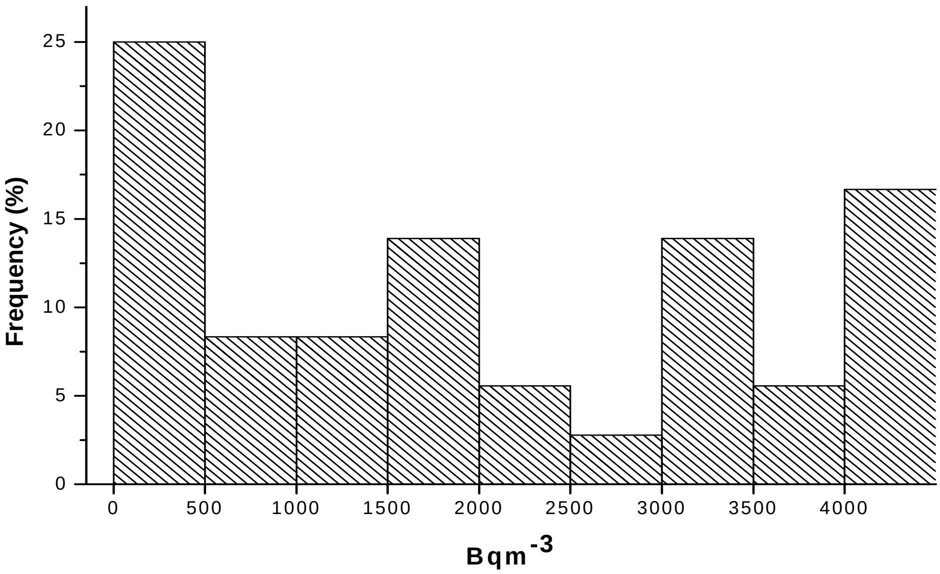

Figure 3. Frequency percent distribution of radon concentration in Dikili Geothermal Region. The last column represents the radon concentration greater than 4000 Bq m^{-3}.

Table 1. The comparison of ^{222}Rn activities for soil with other studies.

Radon Activity (Bq m^{-3})	Study	Country
1657-1855	H. Chaudhuri *et al.* [13]	India
1500-15900	V.M. Choubey *et al.* [50]	India
800-26700	K.M. Abumurad *et al.* [43]	Jordan
1700-24000	V.S. Iakovleva *et al.* [51]	Russia
9910-42100	P. Amponsah *et al.* [52]	Ghana
5500-8700	M. Ngachin *et al.* [53]	Cameroon
6800-74700	J. Chen *et al.* [54]	Canada
209-7389	Erees *et al.* [14]	Turkey
4300-9800	Inceoz *et al.* [47]	Turkey
98-8594	***This Study***	***Turkey***

^{238}U, ^{232}Th and ^{40}K concentrations and dose estimations

The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in stations are shown in table 2. The worldwide average concentrations of ^{238}U, ^{232}Th, ^{40}K are given by UNSCEAR [1] as 35, 30 and 400 Bq kg^{-1}, respectively. The mean value of terrestrial radionuclides in Dikili Geothermal Region was found to be 28.7 Bq kg^{-1} for ^{238}U, 17.6 Bq kg^{-1} for ^{232}Th and 579.2 Bq kg^{-1} for ^{40}K. As can be seen in table 2, while the mean activity concentrations of ^{238}U and ^{232}Th for Dikili Geothermal Region are lower than the world's average values, the mean ^{40}K activity concentration is higher than the world's average. The higher concentration is accepted to be normal by several researchers [48] because of the high usage of fertilizers those have potassium. The uncultivated areas effect from this fertilization process due to transportation with wind and underground waters.

Table 2. The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in four stations.

Sampling Station	Average Activity Concentrations		
	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Zeytindalı	26.5±5	12±3	434.7±21
Nebiler	16.6±4	17.1±4	637.3±25
Çamur	40.3±6	41.2±5	836.3±29
Bademli	31.3±6	ND	408.4±20
Mean Value	28.7±3	17.6±2	579.2±12

Analyses showed that the activity concentrations vary depending on the geological and geographical conditions of different regions. It was found that the activity concentration of ^{238}U, ^{232}Th in Çamur was slightly higher than the World's average [1]. The higher activity concentrations observed in Camur may be due to the higher uranium and thorium content in rock and soil structure in these areas. In addition, the mineralogical and geochemical composition of the soil can affect on the radioactivity levels of Camur.

The absorbed gamma dose rates in the air at 1 m above the ground surface were calculated according to the following formula [1]:

$$D = 0.461(C_U) + 0.623(C_{Th}) + 0.0414(C_K)$$

Where *D (nGyh^{-1})* is dose rate, C_U, C_{Th} and C_K are the activity concentrations of U, Th, K (in Bq kg^{-1}), respectively. The conversion factors used to calculate the dose rate are proposed by UNSCEAR [2]. The calculated outdoor gamma dose rates ranged between 31.4 and 78.9 nGyh^{-1}. The average absorbed dose rate in the air in Çamur was found to be 78 nGyh^{-1} which was higher than the world average (57 nGy h^{-1}). The annual effective dose, *E(μSy^{-1})* was calculated using the Formula given below

$$E = D \times 0.7 \times 8760 \times 0.2$$

where, 0.7 is the conversion coefficient from absorbed dose in air to effective dose received by adults and 0.2 is the outdoor occupancy factor [1].

The calculated annual effective dose equivalents were found to be 46.2, 54.8, 96.8 and 38.4 μSvy^{-1} for Zeytindali, Nebiler, Çamur and Bademli, respectively. From these, the average annual effective dose equivalent was found to be 59.1 μSvy^{-1} for Dikili Geothermal Region. The world average annual effective dose equivalent from outdoor terrestrial gamma radiation is 70 μSvy^{-1} according to UNSCEAR. Thus the average annual effective dose for Camur is higher than the worldwide average [1].

The calculated dose rates and annual effective dose from ^{238}U, ^{232}Th, ^{40}K in surface soil collected from sampling stations were summarized in table 3.

The comparison of average activity concentrations and annual effective dose with the reports of different studies carried out in Turkey and the world were given in table 4. As can be seen, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K radionuclides determined in this study are comparable to other studies from other part of Turkey and world. Studies indicate an average outdoor terrestrial gamma dose rate of 60 $nGyh^{-1}$ in the world ranging from 10 to 200 $nGyh^{-1}$ (1). In this study the average terrestrial gamma dose rate determined as 48.2 $nGyh^{-1}$ and this was lower than the world's average.

Other studies presented in table 4 show that ^{40}K concentrations in soil are significantly higher than ^{238}U and ^{232}Th concentrations. Our result exhibits similar behaviour. The mean concentration of ^{40}K in Dikili Geothermal Area was found to be 579.2 $Bqkg^{-1}$ that is higher than concentration of ^{238}U and ^{232}Th.

Table 3. The calculated absorbed gamma dose rate and annual effective dose.

Stations	Dose Rate ($nGyh^{-1}$)	Annual Effective Dose (μSvy^{-1})
Zeytindalı	37.7	46.2
Nebiler	44.7	54.8
Çamur	78.9	96.8
Bademli	31.4	38.4
Mean	48.2	59.1

CONCLUSION

The activity concentration of terrestrial radionuclide (U^{238}, Th^{232}, K^{40}) and Rn^{222} in soil were measured in four geothermal area located in Dikili Geothermal Region. Based on ^{238}U, ^{232}Th, measurements, it can be said that the average activity concentration of these radionuclides are lower than world averages, expect ^{40}K. However, this value of ^{40}K concentration can be accepted to be normal because of the high usage of fertilizers those have potassium. The results of the present work indicate that the radionuclide activity concentrations of the soil samples varied within the study area due to the differences of geological structures.

The mean absorbed dose rate and the average annual effective dose equivalent due to naturally occurring radionuclides in Dikili Geothermal Region were lower than the world averages. The soil gas radon levels also lie within normal levels compared to national values. It is possible to state that the low levels of radon concentration observed in all investigated geothermal springs is a direct consequence of the geological structure of soils. The maximum radon concentration for soils is recorded during summer season, whereas the minimum was observed in the winter.

In summary, all studied geothermal areas in Dikili are radiology safe; none of them exceeds the recommended action level. This study would be useful for establishing base line data on the natural radioactivity levels in different areas of

Table 4. The comparison of average activity concentrations and annual effective dose with the reports of different studies carried out in Turkey and the world.

Study	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	D ($nGyh^{-1}$)	AED (μSvy^{1})
Present Study	***28.7***	***17.6***	***579.2***	***48.2***	***59.1***
Baldık *et al.*(16)	21	23.5	363.5	39.0	47.9
Baykara *et al.*(25)	79	62	574	100	-
Degerlier *et al.*(18)	17.6	21.1	297.5	67	82
Kam *et al.*(19)	32.9	27.2	431.4	48	33
Taskın *et al.*(22)	28	40	667	71	87
Erees *et al.*(21)	28.5	27	340	43.7	53.5
Santawamaitre *et al.*(55)	35	30	400	57	70
Jankovic *et al.*(56)	64	41	536	69	84.8
El-Aydarous *et al.* (57)	23.8	18.6	460	29	35.6
Mireles *et al.* (58)	23	19	530	44.2	54.2

Dikili.

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