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## Radionuclide determination and radioactivity evaluation of surface soil samples collected along the Erçek Lake basin in eastern Anatolia, Turkey

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### Abstract

In the present study, the mean activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and fission products  $^{137}\text{Cs}$  in the soil samples measured by using high-purity germanium gamma spectrometry were 18.9, 27.2, 524.0 and 10.6 Bq kg<sup>-1</sup>, respectively. The activity results were analyzed for frequency distribution, tabulated and compared with Turkey and worldwide literatures. Radiological risk evaluation was done by calculating absorbed gamma dose rate in outdoor air and the corresponding annual effective dose due to external exposure to radionuclides distributed in soil. The mean values of the outdoor gamma dose rates and the external annual effective doses received by members of the public from terrestrial radiation and  $^{137}\text{Cs}$  were estimated as 47 nGy h<sup>-1</sup> and 0.6 nGy h<sup>-1</sup> and 57.7 µSv and 1.2 µSv, respectively.

**Keywords:** Erçek Lake; Soil; Terrestrial radionuclides;  $^{137}\text{Cs}$ ; External exposure;

Annual effective dose

### 1. Introduction

Natural occurring radionuclides, also called terrestrial or primordial radionuclides, are present in varying amounts in the earth's crust (soils and rocks). Terrestrial radionuclides consist of the decay radionuclides in the series of uranium ( $^{238}\text{U}$ ) and thorium ( $^{232}\text{Th}$ ) and a non-series decay natural radionuclides such as  $^{40}\text{K}$ ,  $^{87}\text{Rb}$ ,  $^{138}\text{La}$ ,  $^{147}\text{Sm}$ , and  $^{176}\text{Lu}$ . The main contribution to external exposure in outdoor from gamma radiation emitted these terrestrial

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radionuclides mainly  $^{238}\text{U}$  and  $^{232}\text{Th}$  series and  $^{40}\text{K}$  (UNSCEAR, 2008). Artificial radionuclides can also be present from the testing of nuclear weapons and the accidents at nuclear reactors, and discharges of radioactive waste from the nuclear installations. In consequence of radioactive fallout after the Chernobyl nuclear reactor accident in 1986,  $^{137}\text{Cs}$  radionuclide ( $T_{1/2}=30.07$  y) was widely dispersed in the Turkish environment (Turhan *et al.*, 2012).

Knowledge of activity levels of the natural and artificial radionuclides is necessary in evaluating of public exposure and ascertaining possible changes in environmental radioactivity caused by nuclear, industrial and other human activities (Turhan *et al.*, 2012). Therefore, the activity concentrations of the natural and artificial radionuclides in soil samples were measured in many studies executed worldwide (UNSCEAR, 2008). Recently, there has been great concern about radiological risks with the external exposure due to the radioactivity in environmental samples in Turkey (Merdanoglu and Altinsoy, 2006; Kılıç *et al.*, 2008; Belivermis *et al.*, 2008; Celik *et al.* 2009; Kucukomeroglu *et al.*, 2009; Damla *et al.*, 2010; Otansev *et al.*, 2012; Tufan and Bostancı 2012; Uğur *et al.*, 2012). The purpose of the study is twofold: first to ascertain the background radiation level of Erçek Lake basin measuring the activity concentration of the  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  in soil samples collected from Erçek Lake basin, about 170 km away from the Metsamor nuclear power plant in Armenia; and second to evaluate the radiological risks associated to these radionuclides by estimating the outdoor gamma-absorbed dose rate ( $D_{\text{out}}$ ) and the external annual effective dose ( $E_{\text{ext}}$ ). This is the first such study in Erçek Lake basin, and so the present study represents baseline data for the area.

## 2. Material and methods

### 2.1. Survey area

Erçek Lake (38°40'33" N and 43°34'45" E) is located at 20 km east of Van Lake, eastern part of Turkey (Fig. 1a). The lake is at a mean altitude of 1803 m covers an area of 106.2 km<sup>2</sup>. Its depth is between 30 m to 38 m (Adıgüzel and Durmuş 2009). Erçek Lake was formed as a result of the volcanic eruption of Nimrod Mountain. The signs of different geological formations from Paleozoic to present time have been seen in the surroundings of it. In the research area the latest sediments of paleotectonic period are lower Miocene age and they are representing the latest marine units of the region. Furthermore, the Ophiolite Nappe, Yüksekova Complex and Bitlis Metamorphites with mantle rocks which overlies the sediment of paleotectonic period represent important information about the geomorphology of the area (Duman and Çiçek 2012). According to national and international marshy grouping, Erçek Lake is an important bird area (Adıgüzel and Durmuş 2009).

## *2.2. Sampling and sample preparation*

Thirty-four surface soil samples at a depth of 0-10 cm range were collected from the Erçek Lake basin on random basis, as shown in Fig. 1b, to determine the distribution of the natural and artificial radionuclides in the surveyed area. The samples were stored in plastic bags and were properly coded according to the sampling location coordinate before being transferred to Gülten Günel Nuclear Physics Research Laboratory at the Physics Department of Cukurova University. Coordinates of sampling locations were determined using a GPS device. After cleaning the stones, vegetation and organic debris, the samples were dried in an oven at 100°C for 24 h. The dried samples were grounded with pestle and then passed through 100 µm mesh sieve. Then, the homogenized samples were placed in plastic containers, weighed, hermetically sealed and stored for a period of four weeks to get secular radioactive equilibrium among the daughter products of radon, thoron and their short lived decay products.

### 2.3. Procedure for activity measurement

For the measurement of activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  in the soil samples, a high-resolution gamma-ray spectrometer with a high purity germanium (HPGe) detector was used. The detector has a relative efficiency of 50% and resolution of 2.0 keV at 1332.5 keV gamma-ray line of  $^{60}\text{Co}$ . The peak-to-Compton ratio is 60:1. For gamma-ray shielding, a front opening split-top shield was used to reduce the background. It features 100 mm lead thickness, which is jacketed by a 9.5-mm steel outer housing. The graded liner comprises 1-mm-thick tin layer and 1.5-mm-thick copper layer to prevent interference by lead X-rays. The detector was interfaced to the digital spectrum analyzer (DSA-1000), which was a full-featured 16K channel multichannel analyzer on advanced digital signal processing (DSP) techniques. DSA-1000 operates through Genie-2000 gamma spectroscopy software including peak searching, peak evaluation, energy/efficiency calculation mode, nuclide identification, and etc. (Uğur *et al.*, 2012).

The reference materials RGU-1, RGTh-1, RGK-1 and soil 375 were employed for the calibration of the measurement system. Spectrum of each sample was collected for 86400 seconds.

The gamma background at the laboratory taken under the same conditions of sample measurements were subtracted from the measured gamma-ray spectra of each sample in order to get net counts for the sample. The activity concentrations were averaged from gamma-ray peaks at several energies assuming secular equilibrium in the  $^{238}\text{U}$  and  $^{232}\text{Th}$  decay series. The activity concentration of  $^{238}\text{U}$  was determined by measuring gamma-ray peak of the 351.9 keV from  $^{214}\text{Pb}$  and the 609.3 keV from  $^{214}\text{Bi}$ . The gamma-ray peak of the 911.2 keV from  $^{228}\text{Ac}$  and the 583.2 keV from  $^{208}\text{Tl}$  were used to determine the activity concentration of  $^{232}\text{Th}$ . The activity concentration of  $^{40}\text{K}$  and  $^{137}\text{Cs}$  was determined using their own gamma-ray line at 1460.8 keV and 661.7 keV, respectively.

The uncertainty of the activity concentration ( $\Delta A$ ) was calculated using the following equation:

$$\frac{\Delta A}{A} = \sqrt{\left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta P_\gamma}{P_\gamma}\right)^2 + \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{\Delta M}{M}\right)^2} \quad (1)$$

where  $\Delta N$  is the count rate uncertainty,  $\Delta P_\gamma$  the emission probability uncertainty found in the nuclear data tables,  $\Delta \varepsilon$  the efficiency uncertainty and  $\Delta M$  the weighing uncertainty (Uğur *et al.*, 2012).

### 3. Results and discussion

#### 3.1. Activity concentrations of radionuclides in the soil samples

Table 1 summarizes the values of the activity concentrations of natural ( $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ ) and artificial ( $^{137}\text{Cs}$ ) together with the statistical uncertainty ( $1\sigma$ ) in the soil samples collected along Erçek Lake basin. The mean activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the soil samples were measured as  $18.9 \pm 1.2 \text{ Bq kg}^{-1}$  (8.6 to  $42.6 \text{ Bq kg}^{-1}$ ),  $27.2 \pm 1.7 \text{ Bq kg}^{-1}$  (11.6 to  $53.2 \text{ Bq kg}^{-1}$ ) and  $524.0 \pm 24.3 \text{ Bq kg}^{-1}$  (254.1 to  $771.9 \text{ Bq kg}^{-1}$ ), respectively. The mean concentrations of radionuclides measured in the soil samples are compared with those reported for different parts of Turkey and different countries and Turkish and worldwide mean values in Table 2. From Table 2 the mean activity concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  is comparable with those reported by other studies. The mean activity concentration of  $^{238}\text{U}$  and  $^{232}\text{Th}$  is lower than that of the world mean. The mean activity concentration of  $^{40}\text{K}$  activity is about 30% higher than that of the world mean. The results have shown relatively low level of the activity concentrations of  $^{137}\text{Cs}$  after Chernobyl nuclear accident. The activity concentration of  $^{137}\text{Cs}$  ranged from 0.7 (35.4  $\text{Bq m}^{-2}$ ) to 24.4 (1235.4  $\text{Bq m}^{-2}$ )  $\text{Bq kg}^{-1}$  with a mean of  $10.6 \pm 0.3 \text{ Bq kg}^{-1}$  ( $536.1 \pm 52.1 \text{ Bq m}^{-2}$ ).

SPSS software was used to calculate various statistics parameters related to the activity concentrations of the radionuclides. The mean activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  for all of the sample locations were compared by using Duncan's multiple range tests. For this, surveyed area was divided into 8 parts according to directions (Table 3). The highest activity value of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  was observed in the northeast region while the lowest activity value was observed in the south region. Based on Duncan's test result east and north region may have similar geological structures. Similar argument can be used for geological structure of west-northwest and southeast-southwest regions as well. South and northeast regions differentiate from other regions. As a result, it has been concluded that these two regions may have different geological structures. For artificial radionuclide  $^{137}\text{Cs}$ , the highest and the lowest levels were found in the west and north regions, respectively.

The frequency distributions of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  activity concentrations are shown in Fig. 2. Skewness is a measure of the asymmetry of a distribution of the real-valued random variable. The skewness values for frequency distribution of all radionuclides investigated in this study are positive values. Positive skewness indicates a distribution with an asymmetric tail extending towards values that are more positive. And kurtosis is a measure of the peakedness of the probability distribution of a real-valued random variable. The kurtosis value for frequency distribution  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  are negative whereas the kurtosis value of  $^{238}\text{U}$  is positive. Positive and negative kurtosis indicates a relatively peaked and flat distribution, respectively (Adam *et al.*, 2012). The frequency distributions of these radionuclides are approximately normal distribution.

### 3.2. Outdoor absorbed gamma dose rate

Gamma dose rates in outdoor air at a height of 1 m above the ground surface were estimated using the activity concentrations of the  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  measured in soil

samples and using dose coefficients (in units of nGy h<sup>-1</sup> per Bq kg<sup>-1</sup>) 0.462, 0.604 and 0.0417 for <sup>238</sup>U series, <sup>232</sup>Th series and <sup>40</sup>K, respectively (UNSCEAR, 2008). The outdoor absorbed gamma dose rate ( $D_{out}$ ) is given by equation 2:

$$D_{out} \text{ (nGy h}^{-1}\text{)} = 0.462 \times A_U + 0.604 \times A_{Th} + 0.0417 \times A_K \quad (2)$$

where  $A_U$ ,  $A_{Th}$  and  $A_K$  are the activity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K, respectively in Bq kg<sup>-1</sup>. It is assumed that the dose coefficient for <sup>137</sup>Cs is 9.01 nGy y<sup>-1</sup>/Bq m<sup>-2</sup> (Brígido *et al.*, 1999). The range and mean values of the  $D_{out}$  evaluated for the soil samples are given in Table 4. The values of  $D_{out}$  due to the presence of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in the soil samples ranged from 21.8 to 81.3 nGy h<sup>-1</sup> with a mean of  $47.0 \pm 2.4$  nGy h<sup>-1</sup>. This mean value is about 20% lower than the world mean value of 58 nGy h<sup>-1</sup> given for regular area (UNSCEAR, 2008).

The outdoor absorbed dose rate in air at 1 m from the ground surface due to <sup>137</sup>Cs levels in soil was calculated using the following relation:

$$D_{DCsout} \text{ (nGy h}^{-1}\text{)} = DCF \times A_{Cs} \quad (3)$$

where  $A_{Cs}$  is the activity concentrations of <sup>137</sup>Cs and DCF is the dose conversion factor. This factor is taken as 9.01 nGy y<sup>-1</sup> per Bq m<sup>-2</sup> (Brigido Flores *et al.*, 1999). The values of the outdoor absorbed gamma dose rate ( $D_{Csout}$ ) due to <sup>137</sup>Cs in the soil samples ranged from 0.04 to 1.3 nGy h<sup>-1</sup> with a mean of  $0.6 \pm 0.1$  nGy h<sup>-1</sup>. The contribution of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K to the total outdoor absorbed gamma dose rate are 18%, 35% and 47%, respectively for all soil samples. The contribution of <sup>137</sup>Cs to the total dose has been neglected because its contribution is small.

### 3.3. External annual effective dose

Conversion factor from absorbed dose in air to effective dose and occupancy factor are important for estimation of the external annual effective dose. In this study, a conversion factor of 0.7 Sv Gy<sup>-1</sup> and an outdoor occupancy factor of 0.2, implying that 20% of time is

spent outdoors on average were used to estimate the external annual effective dose from the natural radionuclides (UNSCEAR, 2008). Similarly, a conversion factor  $1.2 \text{ Sv Gy}^{-1}$  was used to estimate the external effective dose due to  $^{137}\text{Cs}$  (Gibson, *et al.*, 1993). The external annual effective doses are determined by equation 3:

$$E_{\text{ext}} (\mu\text{Sv}) = D_{\text{out}} (\text{nGy h}^{-1}) \times 365.25 \text{ d y}^{-1} \times 24 \text{ h d}^{-1} \times 0.2 \times 0.7 \text{ Sv Gy}^{-1} \times 10^{-3} \quad (4)$$

where  $D_{\text{out}}$  is given by Eq.(2). The external annual effective doses due to  $^{137}\text{Cs}$  are calculated using the following equation:

$$E_{\text{Csext}} (\mu\text{Sv}) = D_{\text{Csout}} (\text{nGy h}^{-1}) \times 365.25 \text{ d y}^{-1} \times 24 \text{ h d}^{-1} \times 0.2 \times 1.2 \text{ Sv Gy}^{-1} \times 10^{-3} \quad (5)$$

where  $D_{\text{Csout}}$  is given by Eq.(3). The range and mean values of the  $E_{\text{ext}}$  and  $E_{\text{Csext}}$  evaluated for the soil samples are given in Table 5. From Table 5, the external annual effective doses due to natural radionuclides and  $^{137}\text{Cs}$  in the soil samples range from 26.7 to 99.7  $\mu\text{Sv}$  with a mean value of  $57.7 \pm 3.0 \mu\text{Sv}$  and 0.1 to 2.7  $\mu\text{Sv}$  with a mean value of  $1.2 \pm 0.1 \mu\text{Sv}$  0.53, respectively. The external mean annual effective dose is lower than the worldwide mean annual effective dose of 66  $\mu\text{Sv}$  (UNSCEAR, 2008).

#### 4. Conclusions

The activity concentration levels of the natural and artificial radionuclides were determined in the soil samples collected from Erçek Lake basin using gamma-ray spectroscopy. The results show that the activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  measured in the soil samples are comparable with those measured in other studies and worldwide mean values measured in the earth's crust. Also, the activity concentration of  $^{137}\text{Cs}$  indicates that this artificial radionuclide is still present due to Chernobyl nuclear accident. As concluded from Table 4 and Table 5, the mean values of the outdoor absorbed gamma dose rate and the external annual effective dose fall within the worldwide range. Consequently, considering the distance between Erçek Lake basin and the Metsamor Nuclear Power Plant, the results related to activity concentration levels of terrestrial and

artificial radionuclides can be used as a data baseline for ascertaining possible changes in environmental radioactivity due to nuclear, industrial and other human activities.

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Sample Code	Activity concentration (Bq kg <sup>-1</sup> )			
	<sup>238</sup> U	<sup>232</sup> Th	<sup>40</sup> K	<sup>137</sup> Cs
S1	22.7 ± 1.4	36.6 ± 3.0	711.5 ± 10.4	14.8 ± 0.8
S2	17.4 ± 1.3	29.6 ± 2.6	424.5 ± 7.6	19.7 ± 0.7
S3	21.2 ± 1.0	24.1 ± 1.9	531.8 ± 7.3	18.3 ± 0.6
S4	19.5 ± 1.2	42.0 ± 3.0	725.5 ± 10.4	14.7 ± 0.6
S5	19.6 ± 0.8	29.1 ± 1.9	498.3 ± 6.2	10.6 ± 0.4
S6	28.4 ± 0.9	36.8 ± 2.2	635.4 ± 7.5	10.2 ± 0.4
S7	17.0 ± 1.2	22.4 ± 2.3	430.0 ± 7.5	9.9 ± 0.6
S8	17.6 ± 1.2	23.4 ± 2.1	487.1 ± 7.4	12.1 ± 0.8
S9	21.4 ± 1.4	34.1 ± 2.7	592.1 ± 9.2	9.2 ± 0.6
S10	17.4 ± 1.3	30.2 ± 2.5	418.7 ± 7.6	8.0 ± 0.8
S11	9.0 ± 0.7	11.6 ± 1.1	254.1 ± 4.0	2.9 ± 0.3
S12	42.6 ± 1.7	40.4 ± 3.2	735.6 ± 10.6	18.6 ± 0.8
S13	10.4 ± 0.8	15.0 ± 1.4	348.9 ± 5.7	20.0 ± 0.6
S14	16.0 ± 1.0	27.3 ± 2.1	550.9 ± 7.8	4.0 ± 0.5
S15	14.9 ± 1.1	17.1 ± 2.0	394.3 ± 6.7	7.6 ± 0.6
S16	16.5 ± 1.2	19.1 ± 2.3	373.1 ± 6.8	11.7 ± 0.7
S17	8.6 ± 0.5	15.5 ± 1.0	656.8 ± 7.4	0.7 ± 0.2
S18	26.0 ± 1.3	36.8 ± 2.8	632.9 ± 9.2	6.5 ± 0.6
S19	14.6 ± 1.2	21.2 ± 2.1	473.8 ± 7.8	10.0 ± 0.6
S20	11.4 ± 1.0	16.7 ± 1.7	432.6 ± 7.0	4.6 ± 0.5
S21	14.7 ± 0.7	20.4 ± 1.5	482.8 ± 5.7	18.1 ± 1.9
S22	13.1 ± 0.8	18.6 ± 1.8	526.0 ± 7.7	1.7 ± 0.4
S23	17.5 ± 1.1	20.8 ± 1.9	358.4 ± 6.3	10.0 ± 0.6
S24	14.5 ± 0.6	16.6 ± 1.2	285.1 ± 3.8	3.7 ± 0.3
S25	20.2 ± 1.1	29.5 ± 2.3	369.1 ± 6.4	18.9 ± 0.6
S26	22.8 ± 1.3	37.5 ± 2.8	759.5 ± 10.8	7.8 ± 0.6
S27	18.6 ± 1.2	24.2 ± 2.2	537.9 ± 8.3	13.5 ± 0.5
S28	10.3 ± 0.8	15.4 ± 1.6	496.8 ± 7.2	4.3 ± 0.5
S29	16.1 ± 0.6	24.2 ± 1.5	508.0 ± 6.0	8.8 ± 0.3
S30	15.6 ± 1.2	22.7 ± 2.3	471.5 ± 7.7	7.9 ± 0.7
S31	23.0 ± 1.2	27.8 ± 2.4	510.8 ± 8.2	5.0 ± 0.5
S32	26.6 ± 1.4	45.4 ± 3.2	751.7 ± 10.7	6.4 ± 0.7
S33	20.8 ± 0.8	39.6 ± 2.3	679.8 ± 7.7	15.4 ± 0.4
S34	36.7 ± 1.4	53.2 ± 3.5	771.9 ± 10.4	24.4 ± 0.7
Range (min-max)	8.6 - 42.6	11.6 - 53.2	254.1 - 771.9	0.7 - 24.4
Mean ± SE	18.9 ± 1.2	27.2 ± 1.7	524.0 ± 24.3	10.6 ± 1.0

Table 1

Country	Activity concentration (Bq kg <sup>-1</sup> )			References
	<sup>238</sup> U	<sup>232</sup> Th	<sup>40</sup> K	
Turkey (Kütahya)	33	32	255	Sahin and Cavas, 2008
Turkey (Manisa)	29	27	340	Erees <i>et al.</i> , 2006
Turkey (Giresun)	33	43	733	Celik <i>et al.</i> , 2008
Turkey (Kastamonu)	33	27	431	Kam and Bozkurt, 2007
Turkey (Tekirdağ)	29	39	580	Kam <i>et al.</i> , 2010
Turkey (Çanakkale)	95	110	1273	Kam <i>et al.</i> , 2010
Turkey (Gaziantep)	25	24	289	Osmanlioglu <i>et al.</i> , 2007
Turkey (Şanlıurfa)	21	25	299	Bozkurt <i>et al.</i> , 2007
Turkey (Erçek Lake)	19	27	524	This study
Turkey mean	29	33	449	Turhan <i>et al.</i> , 2012
Armenia	46	30	360	UNSCEAR, 2008
Russian Federation	19	30	520	UNSCEAR, 2008
Worldwide mean	33	45	412	UNSCEAR, 2008

Table 2

Direction	Sample code	Activity concentration (Bq kg <sup>-1</sup> )			
		<sup>238</sup> U	<sup>232</sup> Th	<sup>40</sup> K	<sup>137</sup> Cs
East	S27, S28, S29, S30	15.2	21.6	503.6	8.6
West	S3, S4, S11, S12, S13	20.5	26.6	519.2	14.9
North	S17, S18, S19, S22, S23, S24, S25	16.4	22.7	471.7	7.4
South	S16, S20	14.0	17.9	402.9	8.2
Northeast	S31, S32, S33, S34	26.8	41.5	678.6	12.8
Northwest	S5, S6, S7, S8, S9, S10	20.2	29.3	510.3	10.0
Southeast	S21, S26	18.8	29.0	621.2	13.0
Southwest	S1, S2, S14, S15	17.8	27.7	520.3	11.5

Table 3

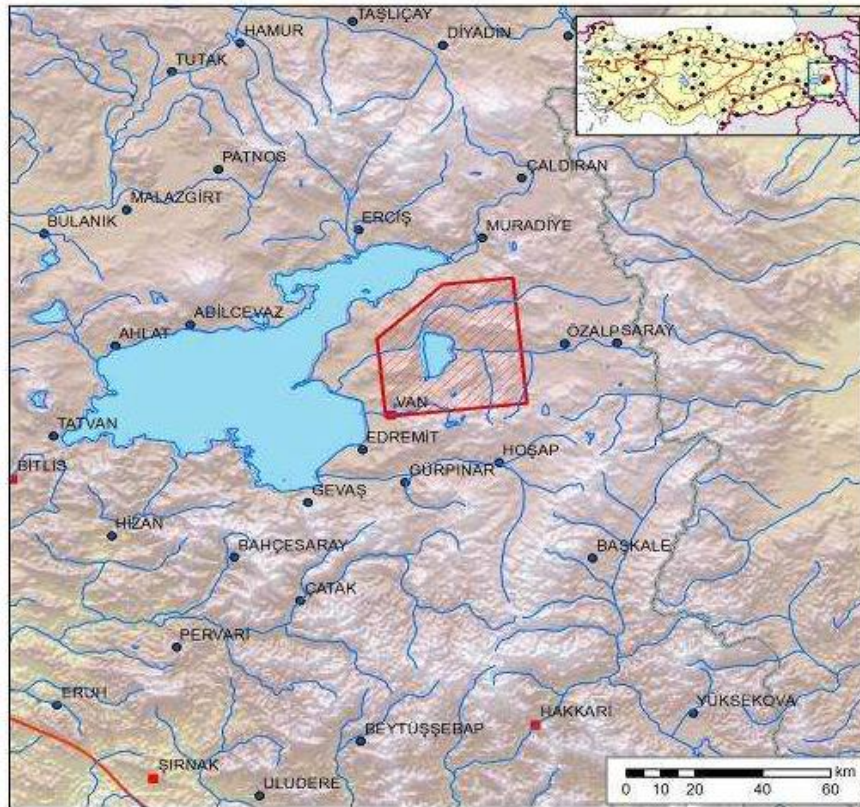
Sample Code	Outdoor absorbed gamma dose rate due to terrestrial radionuclides (nGy h <sup>-1</sup> )	Outdoor absorbed gamma dose rate due to <sup>137</sup> Cs (nGy h <sup>-1</sup> )
S1	62.3	0.8
S2	43.6	1.0
S3	46.5	1.0
S4	64.6	0.8
S5	47.4	0.6
S6	61.8	0.5
S7	39.3	0.5
S8	42.6	0.6
S9	55.2	0.5
S10	43.7	0.4
S11	21.8	0.2
S12	74.8	1.0
S13	28.4	1.0
S14	46.9	0.2
S15	33.7	0.4
S16	34.7	0.6
S17	40.7	0.0
S18	60.6	0.3
S19	39.3	0.5
S20	33.4	0.2
S21	39.2	0.9
S22	39.2	0.1
S23	35.6	0.5
S24	28.6	0.2
S25	42.5	1.0
S26	64.9	0.4
S27	45.6	0.7
S28	34.8	0.2
S29	43.2	0.5
S30	40.6	0.4
S31	48.7	0.3
S32	71.1	0.3
S33	61.9	0.8
S34	81.3	1.3
Range (min-max)	21.8 - 81.3	0.04 - 1.3
Mean ± SE	47.0 ± 2.4	0.6 ± 0.1

Table 4

Sample Code	Annual effective dose from terrestrial radionuclides ( $\mu\text{Sv}$ )	Annual effective dose from $^{137}\text{Cs}$ ( $\mu\text{Sv}$ )
S1	76.4	1.6
S2	53.5	2.2
S3	57.1	2.0
S4	79.3	1.6
S5	58.2	1.2
S6	75.9	1.1
S7	48.2	1.1
S8	52.3	1.3
S9	67.7	1.0
S10	53.7	0.9
S11	26.7	0.3
S12	91.7	2.0
S13	34.9	2.2
S14	57.5	0.4
S15	41.3	0.8
S16	42.6	1.3
S17	50.0	0.1
S18	74.4	0.7
S19	48.2	1.1
S20	41.0	0.5
S21	48.2	2.0
S22	48.1	0.2
S23	43.7	1.1
S24	35.1	0.4
S25	52.2	2.1
S26	79.6	0.9
S27	56.0	1.5
S28	42.7	0.5
S29	53.1	1.0
S30	49.8	0.9
S31	59.8	0.5
S32	87.2	0.7
S33	75.9	1.7
S34	99.7	2.7
Range (min-max)	26.7 - 99.7	0.1 - 2.7
Mean $\pm$ SE	57.7 $\pm$ 3.0	1.2 $\pm$ 0.1

Table 5

a)



b)



Fig. 1

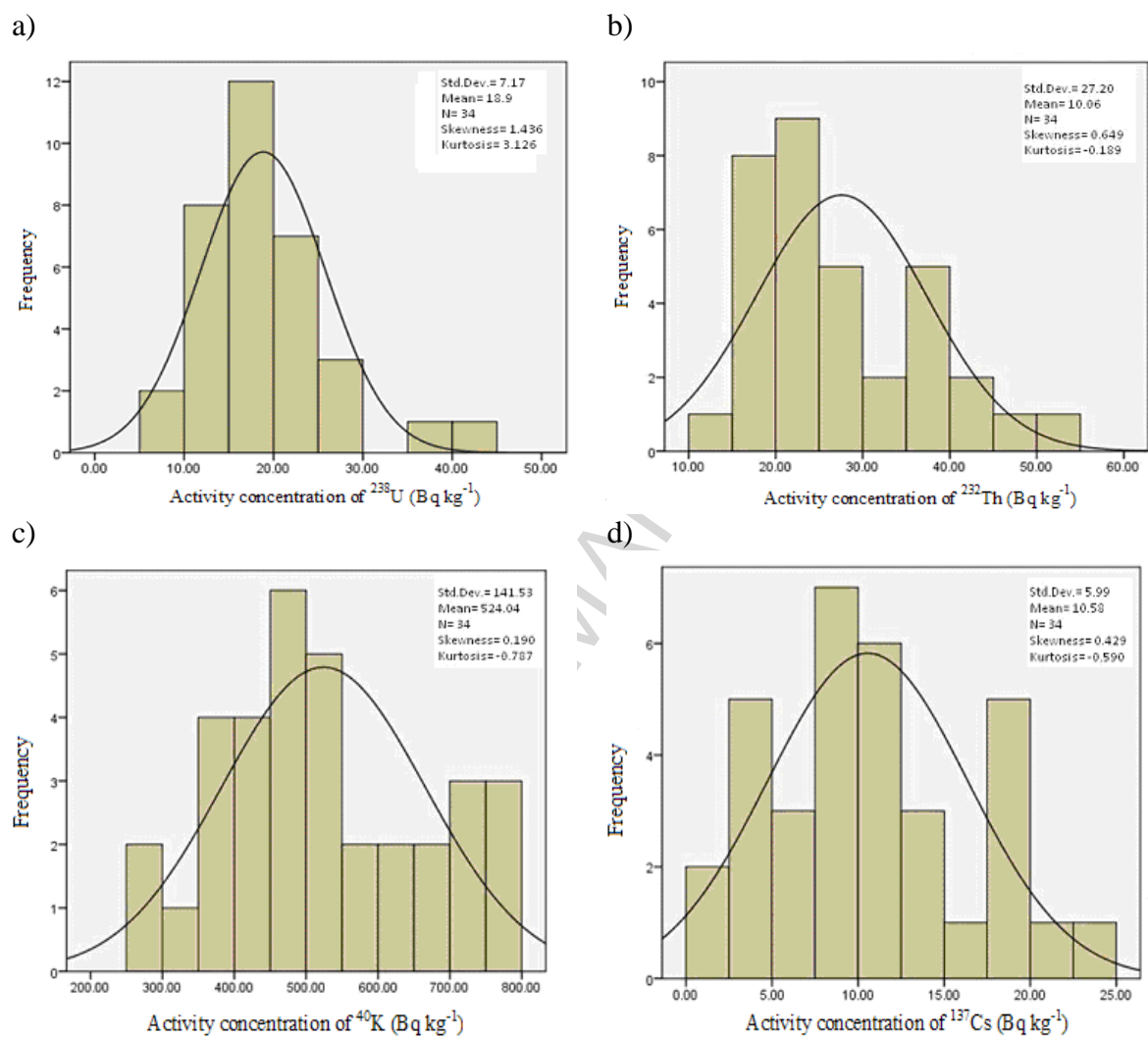


Fig. 2

**TABLE CAPTIONS**

Table 1

The activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  in the soil samples at different locations in the area of Erçek Lake basin

Table 2

Comparison of the activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in surface soil samples with those reported for different regions of Turkey and other countries

Table 3

Distribution of the radionuclides measured in the soil samples according to the directions of the surveyed area

Table 4

The outdoor absorbed gamma dose rates due to gamma radiation emitted from terrestrial radionuclides and  $^{137}\text{Cs}$  estimated for the soil samples

Table 5

The external annual effective doses from terrestrial radionuclides and  $^{137}\text{Cs}$  estimated for the soil samples

**FIGURE CAPTIONS**

Fig. 1

- (a) Map of Erçek Lake showing the area surveyed (taken from Duman and Çiçek 2012),
- (b) Locations of soil sampling throughout Erçek Lake basin

Fig. 2

Frequency distribution of the activity concentration of  $^{238}\text{U}$  (a),  $^{232}\text{Th}$  (b),  $^{40}\text{K}$  (c) and  $^{137}\text{Cs}$  (d) in the soil samples.

**Highlights**

- The study presents the activity of natural and artificial radionuclides in soil samples.
- The activity concentrations of radionuclides are measured by gamma spectrometer.
- Absorbed gamma dose rate from natural and artificial radionuclides is estimated
- Annual effective dose due to external exposure is estimated.
- In this study, the regional scale radioactivity map is produced.

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