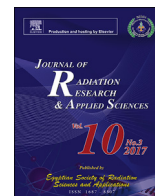


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Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey

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ABSTRACT

In this study, the activity concentrations of naturally occurring ^{40}K , ^{238}U , and ^{232}Th radionuclides and of the artificial, Chernobyl accident-induced ^{137}Cs radionuclide were measured in soil samples collected from Rize Province in the Black Sea region of Turkey.

Rize is a city located in the Northeastern District of Turkey, which was significantly affected by the 1986 Chernobyl nuclear reactor accident in Ukraine, and the effects have continued to today. Tea is the main production plant of the region, and was contaminated by the artificial radioactivity. Therefore, measurements of residual ^{137}Cs contamination in soil are critical for monitoring the potential impacts on human health.

The activity concentrations of radionuclides in 24 soil samples from the study area were measured by means of gamma spectrometry with a NaI(Tl) detector. The activity concentrations in soil samples varied in the range of 7.4–79.8 Bq kg⁻¹ for ^{238}U , 9.5–170.8 Bq kg⁻¹ for ^{232}Th , 35.7–913.8 Bq kg⁻¹ for ^{40}K , and 0.6–154.3 Bq kg⁻¹ for ^{137}Cs . The gamma absorbed dose rates in air were in the range of 10.7–156.4 nGy h⁻¹, with an arithmetic mean of 56.9 nGy h⁻¹, while the annual effective dose rates were determined to be in the range of 13.1–191.8 μSv y⁻¹. The calculated values of external hazard index (H_{ex}) for the soil samples in the study area were in the range of 0.12–0.94. The average value of radium equivalent activity was 125.0 Bq kg⁻¹.

The activity concentrations of radionuclides in soil samples were compared to the international values reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) and previous studies on the area.

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1. Introduction

Since its genesis, the Earth's crust has contained radionuclides with long half-lives, such as ^{40}K , ^{238}U , and ^{232}Th . As a result of their radioactivity, those radionuclides cause natural radiation.

Determination of the activity levels of the radionuclides mentioned above in the soils, waters, local vegetation, and air of a region can help determine the natural radioactivity in a region. Soil is one of major sources of radiation exposure to a population via the transfer of radionuclides into the environment (Ahmad, Jaafar, Bakhash, & Rahim, 2015). The eastern Black Sea region meets 100% of Turkey's tea supply, 60% of which is from Rize Province,

reflecting the fact that tea plants are the main vegetation type in the region. Therefore, analyzing the soil samples is of great importance for tea and other agricultural products such as hazelnut, corn, etc.

Environmental radiation measurements aim to determine the dose of radiation exposure from environmental sources, and to evaluate the health risks posed by radiation. Similar studies have been conducted periodically in the same region in order to update the previous studies and to investigate any changes (Dizman, Görür, & Keser, 2016; Keser et al., 2011; Kurnaz et al., 2007; TAEK, 2007; Turhan et al., 2012; Çelik, Çevik, Çelik, & Koz, 2009). It is crucial to determine the natural radioactivity of the ^{40}K , ^{238}U , and ^{232}Th radionuclides, and particularly, the ^{137}Cs radioactivity occurring in the soil as a result of the nuclear power plant accident in 1986 at the town of Chernobyl in Kiev Province of Ukraine. The eastern Black Sea region was selected for study because of its close proximity to Chernobyl and its contribution to tea production in Turkey.

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Repeating the studies in same the region also enables investigators to monitor time-dependent changes in the concentrations of the ^{137}Cs isotope and to assess the health risks posed by its radioactivity (TAEK, 1988).

The activity concentrations of, ^{238}U , ^{232}Th and ^{40}K natural radionuclides and ^{137}Cs radionuclide were calculated using the analyzed values of the radionuclides and other required data. The results were compared to the data reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) and previous studies for the average mass concentrations of the ^{40}K , ^{238}U , and ^{232}Th radionuclides in soil (Table 2). In addition, the rates of the gamma exposure doses, total effective dose rates, radium equivalent activity and maximum external hazard index were calculated in accordance with the model recommended by UNSCEAR (2000), and presented in Table 3.

2. Materials and methods

2.1. Study area

Rize is a province of Turkey located at the eastern end of the Eastern Black Sea shoreline in northeastern Anatolia (See Fig. 1), between $40^{\circ}22'$ and $41^{\circ}28'N$ of latitude and $40^{\circ}20'E$ and $41^{\circ}20'E$ of longitude. Excluding its lakes, the surface area of Rize is 3922 km^2 , and its population is 328,979. (ÇED Report, 2006).

The study area is characterized by very steep and rough terrain, with 78% of the area being mountainous and elevations ranging from 0 to 2000 m. Rugged terrain dominates the province, and the mountains begin to rise from the coastal sections by the Black Sea. There are a few flat areas in the region, which are located on the coast, or where the river approaches the coast. This region receives the greatest amount of rainfall throughout the year. For this reason, the transport of material in the soil by rainfall and groundwater is important. The locations of the districts where the samples were collected allowed us to survey the natural and artificial radiation in both the coastal and high-altitude regions of Rize.

A total of 24 soil samples (i.e., S1 to S24) were collected for radiation measurements from the Derepaşarı, İyidere, Central Rize,

Table 1
Coordinates and elevations of the sampling locations.

Sample Code	District	N	E	Elevation (m)
S1	İYİDERE	41° 00' 50.9"	40° 22' 16.6"	120
S2	İYİDERE	41° 00' 35.7"	40° 22' 17.2"	129
S3	DEREPAŞARI	41° 01' 29.4"	40° 23' 44.0"	49
S4	DEREPAŞARI	41° 01' 11.8"	40° 23' 21.8"	196
S5	CENTRAL RIZE	41° 02' 01.8"	40° 28' 25.9"	31
S6	CENTRAL RIZE	41° 01' 15.1"	40° 30' 40.4"	107
S7	İKİZDERE	40° 51' 45.5"	40° 28' 07.9"	200
S8	İKİZDERE	40° 47' 00.3"	40° 36' 31.3"	776
S9	KALKANDERE	40° 57' 37.1"	40° 24' 26.9"	75
S10	KALKANDERE	40° 56' 20.7"	40° 25' 50.5"	122
S11	ÇAYELİ	41° 06' 00.6"	40° 44' 16.2"	19
S12	ÇAYELİ	41° 07' 25.4"	40° 45' 33.5"	35
S13	PAZAR	41° 10' 57.6"	40° 53' 40.1"	19
S14	PAZAR	41° 10' 27.5"	40° 51' 07.1"	34
S15	ARDEŞEN	41° 11' 38.6"	40° 58' 50.7"	16
S16	ARDEŞEN	41° 11' 37.6"	41° 00' 16.1"	63
S17	FINDIKLI	41° 15' 15.5"	41° 07' 18.1"	5
S18	FINDIKLI	41° 16' 55.1"	41° 09' 30.8"	26
S19	ÇAMLIHEMŞİN	41° 03' 10.5"	41° 00' 09.7"	204
S20	ÇAMLIHEMŞİN	41° 02' 24.1"	41° 02' 16.4"	303
S21	HEMŞİN	41° 04' 00.9"	40° 53' 35.9"	264
S22	HEMŞİN	41° 02' 41.7"	40° 54' 07.4"	348
S23	GÜNEYSU	40° 59' 02.6"	40° 36' 37.7"	151
S24	GÜNEYSU	40° 58' 13.1"	40° 37' 24.2"	212

Table 2

The radioactivity concentrations A (in Bq kg^{-1}) in the soil samples from the districts of Rize.

Sample code	U-238 (Bq kg^{-1})	Th-232 (Bq kg^{-1})	K-40 (Bq kg^{-1})	Cs-137 (Bq kg^{-1})
S1	49.3 ± 1.5	87.2 ± 5.2	341.1 ± 9.0	36.3 ± 1.7
S2	17.6 ± 2.0	55.5 ± 3.3	584.3 ± 16.6	–
S3	16.2 ± 1.5	49.3 ± 3.0	722.5 ± 20.7	3.3 ± 0.2
S4	18.1 ± 1.9	42.0 ± 2.5	276.8 ± 7.4	2.2 ± 0.2
S5	79.8 ± 9.1	131.3 ± 7.9	338.2 ± 10.4	–
S6	34.3 ± 3.2	79.3 ± 4.8	199.6 ± 6.1	154.3 ± 4.7
S7	19.4 ± 1.6	59.8 ± 3.6	485.9 ± 14.0	3.4 ± 0.2
S8	32.8 ± 2.8	170.8 ± 10.2	913.8 ± 29.7	–
S9	25.3 ± 2.6	109.5 ± 6.6	763.6 ± 19.1	3.7 ± 0.3
S10	16.5 ± 1.5	58.8 ± 3.5	191.7 ± 5.6	8.1 ± 0.3
S11	7.9 ± 0.8	22.1 ± 1.3	240.5 ± 6.8	1.5 ± 0.1
S12	8.8 ± 0.8	11.0 ± 0.7	77.2 ± 2.5	18.7 ± 0.7
S13	9.5 ± 0.9	16.1 ± 1.0	234.1 ± 6.6	6.5 ± 0.2
S14	16.8 ± 1.4	33.7 ± 2.0	158.7 ± 4.6	42.9 ± 1.4
S15	34.2 ± 2.7	44.0 ± 2.6	231.1 ± 6.7	–
S16	7.4 ± 0.7	9.5 ± 0.6	35.7 ± 1.8	14.3 ± 0.5
S17	11.9 ± 1.0	16.3 ± 1.0	173.1 ± 5.0	15.2 ± 0.6
S18	33.9 ± 3.0	34.8 ± 2.1	166.2 ± 4.8	40.4 ± 1.3
S19	57.1 ± 6.5	60.1 ± 3.6	527.7 ± 14.8	30.5 ± 1.1
S20	13.9 ± 1.5	27.1 ± 1.6	583.8 ± 16.7	83.5 ± 2.6
S21	10.2 ± 1.0	21.3 ± 1.3	141.0 ± 8.6	3.8 ± 0.3
S22	10.3 ± 0.9	18.9 ± 1.1	92.6 ± 2.7	1.9 ± 0.2
S23	33.8 ± 3.4	27.9 ± 1.7	343.0 ± 9.6	55.8 ± 1.7
S24	23.6 ± 2.2	54.5 ± 3.3	454.7 ± 12.7	0.6 ± 0.1
Mean	24.5	51.8	344.9	26.3
UNSCEAR, 2000	35	30	400	51
Dizman et al., 2016	85.8	51.1	771.6	236.4
Keser et al., 2011	51.1	72.4	229.3	312.9
Çelik et al., 2009	55.2	40.9	622.8	169.7

Table 3

Absorbed dose rates, radium equivalent activities, external hazard indexes and annual effective dose rates for the districts of Rize Province.

Sample Code	D (nGy h^{-1})	R_{eq} (Bq kg^{-1})	H_{ex} (nGy h^{-1})	AEDR ($\mu\text{Sv y}^{-1}$)
S1	89.7	200.2	0.54	109.9
S2	66.0	141.9	0.38	80.9
S3	67.4	142.4	0.38	82.7
S4	45.3	99.5	0.27	55.5
S5	130.3	293.6	0.79	159.8
S6	72.1	163.1	0.44	88.4
S7	65.3	142.3	0.38	80.1
S8	156.4	347.4	0.94	191.8
S9	109.7	240.7	0.65	134.5
S10	51.1	115.3	0.31	62.7
S11	27.1	58.1	0.16	33.2
S12	13.9	30.5	0.08	17.1
S13	23.9	50.6	0.14	29.3
S14	34.8	77.3	0.21	42.6
S15	52.0	115.0	0.31	63.8
S16	10.7	23.8	0.06	13.1
S17	22.6	48.5	0.13	27.7
S18	43.6	96.4	0.26	53.5
S19	84.7	183.7	0.50	103.8
S20	47.2	97.7	0.26	57.8
S21	23.5	51.5	0.14	28.8
S22	20.0	44.4	0.12	24.5
S23	46.8	100.2	0.27	57.4
S24	62.8	136.6	0.37	77.0
Arithmetic Mean	56.9	125.0	0.34	69.8

İkizdere, Kalkandere, Çayeli, Pazar, Ardeşen, Fındıklı, Çamlıhemşin, Hemşin, and Güneysu districts of Rize. Samples were collected from two different elevations in each district from the region and the coordinates of each sampling location were recorded. Table 1 shows the locations from which the soil samples were collected.

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