



Natural radioactivity in soil samples taken from Kahramanmaraş provincial center

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Received: 6 September 2022 / Accepted: 12 April 2023 / Published online: 26 April 2023
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Abstract The levels of ^{238}U , ^{232}Th , and ^{40}K with gross alpha and beta values in soils collected from the Kahramanmaraş city center were measured in this study, and the annual effective dose equivalent (AEDE), excessive lifetime cancer risk (ELCR), and terrestrial absorbed gamma dose rates were calculated for gamma radiation from ^{238}U , ^{232}Th , and ^{40}K radionuclides. The samples' gross alpha and beta radioactivity concentrations, respectively, range from 0.06 ± 0.01 Bq/kg to 0.45 ± 0.04 Bq/kg and 0.14 ± 0.02 Bq/kg to 0.95 ± 0.09 Bq/kg. The Kahramanmaraş province's soil samples have mean gross alpha and beta radiation values of 0.25 ± 0.03 Bq/kg and 0.52 ± 0.05 Bq/kg, respectively. ^{238}U , ^{232}Th , and ^{40}K

activity concentrations in soil samples range from 2.32 ± 0.2 Bq/kg to 40.10 ± 1.4 Bq/kg, 0.60 ± 0.03 Bq/kg to 10.47 ± 1.01 Bq/kg, and 11.60 ± 1.01 Bq/kg to 160.84 ± 4.6 Bq/kg, respectively. ^{238}U , ^{232}Th , and ^{40}K each had average activity concentrations of 11.50 ± 1.1 , 4.50 ± 0.4 , and 62.20 ± 1.6 Bq/kg in soil, respectively. The annual effective dose equivalent (AEDE), excessive lifetime cancer risk (ELCR), and terrestrial absorbed gamma dose rate range from 0.01 ± 0.01 $\mu\text{Sv y}^{-1}$ to 0.03 ± 0.02 $\mu\text{Sv y}^{-1}$, and $0.01 \pm 0.01 \times 10^{-3}$ to $0.12 \pm 0.03 \times 10^{-3}$, 1.72 ± 0.01 nGy h^{-1} to 25.05 ± 0.21 nGy h^{-1} , respectively. Additionally, the average annual effective dose equivalent (AEDE), average excessive lifetime cancer risk (ELCR), and average terrestrial absorbed gamma dose rates are 0.01 ± 0.01 $\mu\text{Sv y}^{-1}$, and $0.05 \pm 0.02 \times 10^{-3}$, 9.81 ± 0.09 nGy h^{-1} , respectively. The acquired data were compared to both domestic and international standards.

Keywords Kahramanmaraş · Radioactivity in soil · Gross alpha and beta · Annual effective dose equivalent · Excessive lifetime cancer risk

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Introduction

The major source of soil radioactivity is rocks. The concentration of radioactivity contained in the soil; weather conditions, sedimentation, filtration, absorption, and precipitation as a result of the movement of

groundwater, irrigation with other substances, and high degree of porosity may increase or decrease. The presence of natural radionuclides in the soil, such as ^{238}U , ^{232}Th , and ^{40}K , makes the soil radioactive. The majority of naturally occurring radionuclides are concentrated in volcanic, phosphate, granite, and salt rocks. Depending on the weather, these rocks erode over time and become extremely minute fragments that mix with the soil when it rains or when water flows through them. By doing this, they raise the soil's inherent radioactivity. Even certain human practices that are utilized in agriculture to boost soil productivity, such as artificial insemination and fertilization (artificial fertilizers include radioactive ^{32}P), raise the soil's localized surface radioactivity (Niewiadomski et al., 1980). Liden & Holm (1985) provide concentrations of ^{40}K , ^{232}Th , and ^{238}U in various rocks and soils. As a result, it can be shown that different types of rocks have different activity concentration quantities of ^{238}U , ^{232}Th , and ^{40}K . The highest ^{40}K and ^{232}Th activity concentration amounts are seen to be in erupted granite rock species, while the highest ^{238}U activity concentration amount is seen to be in sedimentary clay skewers. From this point of view, we can say that granite rocks are rich in potassium and thorium, while clay-swollen rocks are rich in uranium. Therefore, according to the types of rocks under the soil on earth, variations can be seen in the amount and types of radioactivity contained in the soil. In alkaline rocks, another type of rock, uranium, and thorium may also tend to be abundant (Gascoyne, 1992). It is said that uranium and thorium have high concentrations due to the fact that they are rich in quartz in eruption and granite rocks (Valkovic, 2000). In the report published by UNSCEAR, it is estimated that gamma radiation levels are also quite high in places where thorium-rich granite rocks are found in many places (UNSCEAR, 1993).

When the geological structure of the earth is examined, it is seen that there are rock beds just below the soil layer of a certain thickness. These rock deposits are also presumed to cause terrestrial radioactivity. In particular, it is known that a significant part of gamma radiations originate from the surface layer at a depth of 0–25 cm (UNSCEAR, 1993). Significant levels of thorium are present in some regions' granite rocks, which are dispersed across extremely broad areas. According to radiometric studies, the levels of gamma radiation observed in the vicinity of

these rocks are relatively high. The radiation intensity measured in the air in the Colorado region of the USA is around 8–16 $\mu\text{R}/\text{hour}$, in Brazil it is 5–158 $\mu\text{R}/\text{hour}$, in Italy it is 7–50 $\mu\text{R}/\text{hour}$, in Sweden, it is 2–400 $\mu\text{R}/\text{hour}$, in India, it is around 2–110 $\mu\text{R}/\text{hour}$. As can be seen, natural radiation levels are quite high in these countries (UNSCEAR, 1993). The annual radiation doses that people living in these countries receive from natural sources are much higher than in other countries.

The radioactivity present in the soil changes slightly with biochemical processes. While the development of plant root systems provides balance in the soil, on the one hand, it also takes the water that the plant needs from the soil. The disintegration of rocks and their subsequent mixing with soil through water are both processes that depend heavily on humic acid. Oxidations in the soil's bottom layers are where the breakdown of organic materials in the soil starts. Over time, the substrates lose some of their uranium content. Mobility in the soil continues with the formation of iron oxides and other elements. The acid formed in some soils prevents the retention of radionuclides by means of calcium carbonate in the environment. These stages of development in the soil also reduce radionuclide concentrations in rocks and therefore external radiation levels. People are exposed to natural radiation at those rates because of the natural radionuclides in the soil, which alter the natural radiation of the environment or environment according to their percentage in the soil (UNSCEAR, 1982a). Radionuclides that were once present in the earth's crust have relatively low average amounts. Myrick et al., provided activity concentrations of naturally occurring radionuclides in soil (Myrick et al., 1983). As a result, the average activity concentration of ^{40}K in soil is 370 Bq/kg, ^{232}Th in activity is 35 Bq/kg, ^{238}U in activity is 35 Bq/kg, and ^{226}Ra in activity is 40 Bq/kg.

Many studies have been carried out in recent years to determine the level of natural radioactivity in soil and rock samples (Algattawi et al., 2019; Dina et al., 2022; Milena et al., 2022).

This research aims to determine the gross alpha and beta radioactivity values and the activity concentrations of radionuclides (^{238}U , ^{232}Th , and ^{40}K) in soil samples collected in Kahramanmaraş. Additionally, this study aims to calculate terrestrial absorbed gamma dose rate and the annual effective

dose equivalent (AEDE) in soil samples using the activity concentrations of gamma-ray emitting radionuclides (^{238}U , ^{232}Th , and ^{40}K), and to calculate excessive lifetime cancer risk (ELCR). This is the first research to assess the radioactive level of soil samples in Kahramanmaraş's city center. Thus, a basic level was identified in terms of the radioactive level of soil samples in Kahramanmaraş's city center, and it is also added to the existing literature.

Study area

This research was carried out at Kahramanmaraş, Turkey. In terms of population, Kahramanmaraş is Turkey's 11th biggest province. It is Turkey's 18th biggest province with a surface area of 14,327 km². It is situated between the 37–38 northern parallels and the 36–37 eastern meridian. Figure 1 depicts the geographical map of the province of Kahramanmaraş, Turkey, as well as the map of places acquired from the samples (<https://www>.

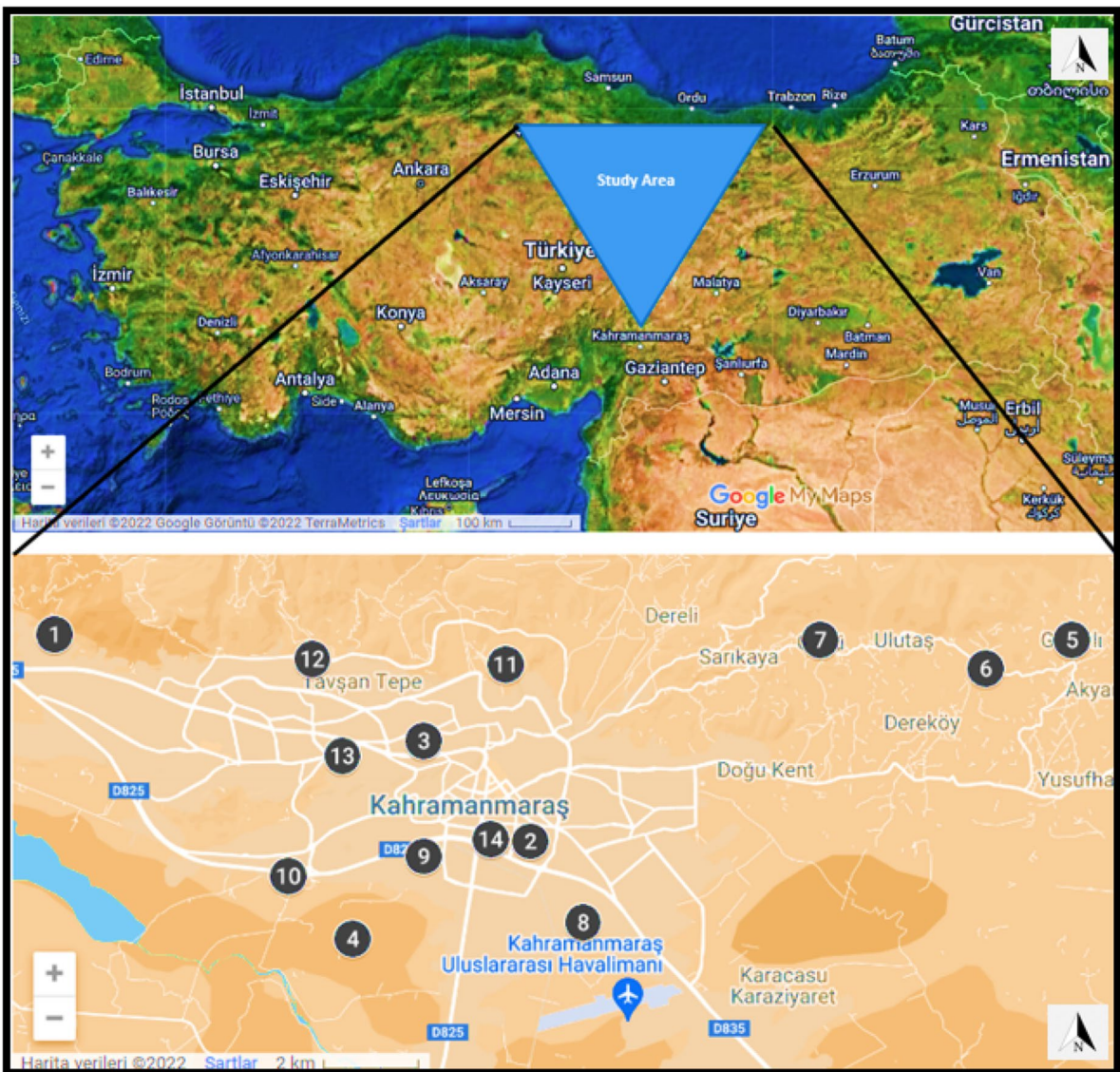


Fig. 1 Turkey, Kahramanmaras, and Study Area-Map (<https://www.google.com/maps/>)

[google.com/maps](https://www.google.com/maps), 2022). For this study, 14 soil samples were collected from 14 different locales of Kahramanmaraş. These locations are in the city center. The locations and geographic coordinates of the places where the samples were taken as in Table 1. A thorough understanding of geology, including bedrock and soil, is required for soil natural radioactivity mapping. So, the places where the samples were taken and the soil and rock structures of these places are given in Table 1.

Materials and methods

With consideration for the sample collection requirements, such as not dumping fertilizer or lime from the areas where soil samples would be taken in and around, and not burning stalks, roots, and weeds, samples were obtained with a garden shovel from a depth of 0–5 cm. While samples were taken in a neighborhood, samples were taken not only from one place but also from several points in the neighborhood and placed in disposable sterile bags, and soil samples of 2 kg weight taken from each neighborhood were mixed homogeneously. Without wasting any time, the soil samples collected as a result of the field investigations were brought to the lab environment, where they were laid out on single-use plastic bags to dry at room temperature for ten days. With this process, the amount of moisture present in the samples was reduced to a minimum. The soil samples wrapped in aluminum foils were then subjected to drying in an oven at 105 °C. It did not participate in the calculations because the amount of radioactivity that would be lost by evaporation during the drying process was negligible. As a result of this process, the soil samples that were completely dried were sifted using a special sieve with 100 mesh pores and labeled in clear plastic bags. Then, each soil sample was transferred to a tared planchette in a quantity that would not cause self-absorption in a way to exhibit a homogeneous distribution, and a quantity of pure water was added to it to prevent sample loss and dried on the electric stove. The samples in the 2-inch-diameter stainless steel planchettes were then dried for approximately 2 h at 105 °C before being kept in a suitable condition until counting. The soil samples were prepared for counting using the aforementioned techniques, and the gross alpha, gross beta, and radioactive contents were determined using the proper counting systems.

Measurement of gross alpha and gross beta activity concentrations

The samples were measured for their gross alpha radioactivity with 7286 low-level alpha counters, and their gross beta radioactivity with windowless scintillation counters. Calibration of counting systems was performed using the pertinent manuals (Bal et al., 2015). For each counting period, the counting time was 3000 s for gross alpha activities and 1000 s for gross beta activities. To calculate total counts for each gross alpha and gross beta activity, three counting periods were chosen. For the purpose of calculation, the background was subtracted from the gross count to produce the net counts. (Karahan, 1997; Dođru and Canbazođlu, 2002; Canbazođlu et al., 2000; Dođru et al., 2002). The concentrations of gross alpha and beta activity in the soil samples were determined using the equations in (3.1) and (3.2) below.

$$A_{\alpha} = \frac{[(NS \pm SS) \times VDF]}{2.22} \quad (3.1)$$

$$A_{\beta} = \frac{[(NS \pm SS) \times VDF]}{2.22} \times E \quad (3.2)$$

In these equations; A_{α} A_{β} : The amount of activity in pCi, NS: is the net count in a minute, SS is: Standard deviation, VDF is: the yield correction factor, 2.22 is the conversion factor (1 pCi = 2.22 dpm), and E is the beta calculated from the corresponding calibration curve is the yield factor (cpm/dpm) (Karahan, 1997; Dođru and Canbazođlu, 2002; Canbazođlu et al., 2000; Dođru et al., 2002). It is given by the equation of yield correction factor (3.3) for the activity counted on the aluminum planchet,

$$VDF = \frac{1}{V \times (T)} \quad (3.3)$$

The value of T in this equation is found from the self-absorption curves for U_3O_8 and KCl drawn according to certain standards as a function of thickness in mg/cm² (Karahan, 1997; Tuncer, 1991). The parameter V in Eq. (3.3) is the yield and is calculated by Eq. (3.3). The following Eq. (3.4) is used to convert the counting rate into decays,

$$dpm = \frac{cpm}{\text{efficiency}} = \frac{cpm}{GBT} = cpm \times (VDF) \quad (3.4)$$

Table 1 Soil and rock structure of the places where soil samples are collected in Kahramanmaraş

Longitude and latitude values for locations	Location (Sample collection place)	Soil structure	Rock structure
37°37'05.3"N, 36°48'26.4"E	Kazma Bağları position	Brown forest soil consists of lime-rich clay stones, mica schists, and gneiss, rich in potassium	Middle Miocene was formed over 7–26 million years ago and composed of limestone, marl, claystone, clayey limestone, sandstone, mudstone, conglomerate, agglomerate, andesite, and tuff
37°34'07.6"N, 36°56'13.8"E	Bahçelievler neighborhood	Alluvial soils that are rich in phosphorus, and potassium, contain clay and the format in which are transported	New alluvial
37°35'09.8"N, 36°54'43"E	Karamanlı neighborhood	Red–brown Mediterranean soil that consists of granite, various metamorphics, claystone, sandstone, limestone, and conglomerate	Slope debris
37°34'09.7"N, 36°54'15.5"E	Barbaros neighborhood	Brown forest soil consists of lime-rich clay stones, mica schists, and gneiss, rich in potassium	Middle Miocene was formed over 7–26 million years ago and composed of limestone, marl, claystone, clayey limestone, sandstone, mudstone, conglomerate, agglomerate, andesite, and tuff
37°36'18.2"N, 37°03'37.9"E	Gaffarlı neighborhood	Brown forest soil consists of lime-rich clay stones, mica schists, and gneiss, rich in potassium	Middle Eocene was formed 38–54 million years ago and contains sandstone, mudstone, pebbles, spilite, serpentine, limestone, and conglomerate
37°35'59.5"N, 37°02'30.8"E	Yassıpınar position	Brown forest soil consists of lime-rich clay stones, mica schists, and gneiss, rich in potassium	Middle Eocene was formed 38–54 million years ago and contains sandstone, mudstone, pebbles, spilite, serpentine, limestone, and conglomerate
37°36'19.2"N, 37°00'15.3"E	Göllü neighborhood	Red–brown Mediterranean soil that consists of granite, various metamorphics, claystone, sandstone, limestone, and conglomerate	Slope debris
37°32'44.3"N, 36°58'07.8"E	Eyüp Sultan neighborhood	Alluvial soils that are rich in phosphorus, and potassium, contain clay and the format in which are transported	New alluvial
37°33'57.7"N, 36°54'44.82"E	Gayberli neighbord	Alluvial soils that are rich in phosphorus, and potassium, contain clay and the format in which are transported	New alluvial
37°34'00.7"N, 36°53'29.4"E	Oruç Reis neighborhood	Alluvial soils that are rich in phosphorus, and potassium, contain clay and the format in which are transported	New alluvial

Table 1 (continued)

Longitude and latitude values for locations	Location (Sample collection place)	Soil structure	Rock structure
37°35'37.5"N, 36°56'05.3"E	Pınarbası neighborhood	Brown forest soil consists of lime-rich clay stones, mica schists, and gneiss, rich in potassium	Middle Miocene was formed over 7–26 million years ago and composed of limestone, marl, claystone, clayey limestone, sandstone, mudstone, conglomerate, agglomerate, andesite, and tuff
37°35'52.3"N, 36°53'19.2"E	Hürriyet neighborhood	Colluvial soils, a clay-containing soil washed from the limestone field and rich in potassium	Slope debris
37°35'01.3"N, 36°53'36.4"E	Akif İnan neighborhood	Red–brown Mediterranean soil that consists of granite, various metamorphic, claystone, sandstone, limestone, and conglomerate	Slope debris
37°34'27.1"N, 36°55'49.7"E	Yenişehir neighborhood	Colluvial soils, a clay-containing soil washed from the limestone field and rich in potassium	Slope debris

where G : Correction factor for geometry, B : Scatter-back correction factor, and T : Self-absorption correction factor. $1/GBT$ is the yield correction factor and is VDF for short.

The thickness varies with the effective area with the mass of the sample and is expressed by the Eq. (3.5),

$$\text{Thickness (mg/cm}^2\text{)} = \frac{\text{(Mass in mg for example)}}{\text{(Active area)}} \quad (3.5)$$

Measurement of radionuclides activity concentrations

A gamma-sensitive scintillation counter was used for concentration counts of the radionuclide activity of the samples. The energy of the uranium or thorium series that is most prevalent is measured along with the amounts of the radionuclides ^{238}U , ^{232}Th , and ^{40}K in the samples. The most abundant radioisotopes of the uranium and thorium series in nature are as follows. ^{226}Ra is a decay product of ^{238}U . There is a photo peak energy with a 36% abundance at 186 keV, according to Degerlier et al. (2008). This photo peak energy does not appear in the spectrum as it is intertwined with the photo peak energy of ^{235}U at 185.7 keV. But it is possible to find it by account. This radionuclide is evaluated separately from ^{238}U in activity measurements (Karahan, 1997). ^{214}Pb is the decay product of ^{238}U and is detected at a photo peak energy of 351 keV at a 36% abundance, according to Degerlier et al. (2008).

^{214}Bi is a decay product of the ^{238}U series, seen at 609 keV with a 45% abundance. ^{228}Ac is a decay product of the ^{232}Th series, for example, there are many peaks at different energies with an abundance of 12% at 338 keV, 911 keV, and 5% at 28.964 keV (Degerlier, et al., 2008). The ^{208}Tl is a decay product of the ^{232}Th series and has the highest abundance at 583 keV with 30.7% despite having many peaks at different energies. ^{40}K is found alone in nature. There is no decay series. It is the natural radioactive element that contributes the most to the natural gamma radiation dose, as it is abundant in soil. At the photo peak energy of 1460 keV, there is an abundance of 11%. In light of this information, for ^{238}U , ^{238}U has ^{214}Bi 609 keV energy, which is a decay product of 45% in nature, and for ^{232}Th , gamma rays with an energy of 583 keV of ^{208}Tl , which is a decay product of the

²³²Th series and has the highest abundance of 30.7% in nature, and gamma rays with 1460 keV energy for ⁴⁰K were used. Each sample was counted for a period of 10 h. Energy calibration of the detector was performed by using ⁶⁰Co (37 kBq) and ²²⁶Ra (370 kBq) point sources. Photo peak efficiency was 24%. ²³⁸U, ²³²Th, and ⁴⁰K activity concentrations. The concentrations of ²³⁸U, ²³²Th, and ⁴⁰K radionuclides in the soil samples were determined using the equation in (3.7) below.

$$A(\text{Bq/kg}) = [C_n] / M_n VP \tag{3.6}$$

A is an activity in Bq/kg; C_n is the net number of counts per minute, M_n is the mass of the sample, V is the efficiency of the detector, and P is the absolute probability of transition of gamma decay (Baykara & Dođru, 2009).

Terrestrial absorbed gamma dose rate (D)

The amount of gamma radiation absorbed by the body each hour as a result of exposure to terrestrial radiation at a height of 1 m above the soil surface is known as the terrestrial absorbed gamma dose rate (D). The following calculation can be used to compute the terrestrial absorbed gamma dose ratio (Beck, 1972).

$$D(\text{nGy h}^{-1}) = 0.427AU + 0.662A\text{Th} + 0.043AK \tag{3.7}$$

where the numbers 0.427, 0.662, and 0.043 are the ²³⁸U, ²³²Th, and ⁴⁰K radionuclide dose coefficients, respectively. The radionuclides ²³⁸U, ²³²Th, and ⁴⁰K's respective activity concentrations are written as AU, ATh, and AK in Bq kg⁻¹ units. The rate of terrestrial absorption gamma radiation for soil samples was estimated in the study and expressed in nGy h⁻¹.

Annual effective dose equivalent (AEDE)

The biological impact of the gamma dose rate received in the air and the radiation dosage to which it is subjected over the course of a year is calculated using the annual effective dose equivalent (AEDE). The following equation is used to determine the annually effective dosage equivalent (UNSCEAR, 1982b, 1988):

$$\begin{aligned} \text{AEDE}(\mu\text{Sv y}^{-1}) &= D(\text{nGy h}^{-1}) \times 8760(\text{h}) \\ &\times 0.2 \times 0.7(\text{Sv Gy}^{-1}) \times 10^{-3} \end{aligned} \tag{3.8}$$

It's important to know how long gamma radiation is exposed when estimating how gamma rays affect living organisms. Exposure time is defined as the occupancy factor. When a year is taken as 365 days and there is radiation exposure for 24 h, people are exposed to 8760 h of radiation for a year. Assuming that an average person spends about 5 h a day outdoors, the busyness factor is taken as 0.2. The coefficient of 0.7 in equity is the coefficient of conversion of air-absorbed dose to effective dose for adults. For each soil sample used in the study, the yearly effective dosage equivalent was determined (Degerlier et al., 2008; UNSCEAR, 1982b, 1988).

Excessive lifetime cancer risk (ELCR)

When a population is exposed to ionizing radiation over the course of a lifetime, there is a chance that cancer may develop. This is referred to as excessive lifetime cancer risk. The formula for calculating excessive lifetime cancer risk (ELCR) is as follows: (Kolo et al., 2017; Taskin et al., 2009).

$$\text{ELCR} = \text{AEDE}(\mu\text{Sv y}^{-1}) \times \text{DL}(\text{y}) \times \text{RF}(\text{Sv}^{-1}) \tag{3.9}$$

where the study's annual active dosage equivalent, is denoted as AEDE, and the average life expectancy is denoted as DL (70 years). 0.057 Sv⁻¹ is used as the value for RF, which stands for the risk of deadly cancer per risk factor Sievert (ICRP, 2007).

Results and discussion

In this section, the gross alpha and gross beta activity as well as the quantities of naturally occurring radioactive nuclei found in 14 soil samples taken from Kahramanmaraş's city center are assessed. These observations identified the ⁴⁰K radioisotope as well as the activity concentrations of the most prevalent components of the ²³⁸U and ²³²Th natural radioactive series. Annual effective dose equivalent (AEDE) for gamma radiation from ²³⁸U, ²³²Th, and ⁴⁰K radionuclides, excess lifetime cancer risk (ELCR), and the

calculated terrestrial absorbed gamma dose rates are also given in the following subheadings.

Gross alpha and beta activity concentrations in soil samples

Table 2 lists the gross alpha and gross beta radiation values of soil samples taken from various areas to describe the Kahramanmaraş city center. When the gross alpha and gross beta radiation levels of soil samples from the province center of Kahramanmaraş are analyzed, the samples' gross alpha radioactivity levels vary from 0.06 ± 0.01 to 0.45 ± 0.04 Bq/kg, and their gross beta radioactivity levels range from 0.14 ± 0.02 to 0.95 ± 0.09 Bq/kg. Figures 2 and 3 display the frequency distribution of soil's gross alpha and beta radioactivity.

Figure 2 shows that the range of gross alpha concentration in five samples was between 0.20 and 0.30 Bq/kg. Additionally, the range of gross alpha content in four samples was 0.10–0.20 Bq/kg. In eight samples, the concentration of gross beta ranged from 0.40 to 0.60 Bq/kg, as shown in Fig. 3. There are two samples with gross beta concentrations ranging from 0.20 to 0.40 to 0.80 to 1.00 Bq/kg.

The Hürriyet neighborhood sample has the greatest gross alpha radiation level at 0.45 ± 0.04 Bq/kg,

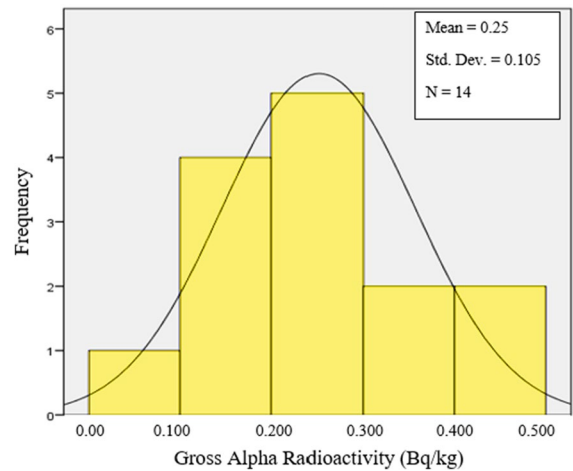


Fig. 2 The frequency distribution of gross alpha radioactivity in soil

while the Kazma Bağları location sample has the lowest gross alpha radioactivity level at 0.06 ± 0.01 Bq/kg, as can be noted. Furthermore, the Karamanlı neighborhood has the lowest gross beta radiation level (0.14 ± 0.02 Bq/kg), whereas the Gaffarlı area has the greatest gross beta radioactivity level (0.95 ± 0.09 Bq/kg). The average gross radioactivity values of the soil

Table 2 Gross alpha and beta radioactivity levels in soil samples in Kahramanmaraş city

Example no	Sample place	Gross alpha radioactivity (Bq/kg)	Gross beta radioactivity (Bq/kg)
1	Kazma Bağları position	0.06 ± 0.01	0.56 ± 0.05
2	Bahçelievler neighborhood	0.36 ± 0.03	0.53 ± 0.05
3	Karamanlı neighborhood	0.15 ± 0.02	0.14 ± 0.02
4	Barbaros neighborhood	0.31 ± 0.03	0.36 ± 0.03
5	Gaffarlı neighborhood	0.41 ± 0.04	0.95 ± 0.09
6	Yassıpınar position	0.28 ± 0.03	0.49 ± 0.04
7	Göllü neighborhood	0.26 ± 0.03	0.62 ± 0.06
8	Eyüp Sultan neighborhood	0.27 ± 0.03	0.92 ± 0.09
9	Gayberli neighborhood	0.17 ± 0.02	0.50 ± 0.05
10	Oruç Reis neighborhood	0.17 ± 0.02	0.43 ± 0.04
11	Pınarbaşı neighborhood	0.20 ± 0.02	0.30 ± 0.03
12	Hürriyet neighborhood	0.45 ± 0.04	0.45 ± 0.04
13	Akif İnan neighborhood	0.22 ± 0.02	0.44 ± 0.04
14	Yenişehir neighborhood	0.21 ± 0.02	0.54 ± 0.05
	Maximum	0.45 ± 0.04	0.95 ± 0.09
	Minimum	0.06 ± 0.01	0.14 ± 0.02
	Mean	0.25 ± 0.03	0.52 ± 0.05

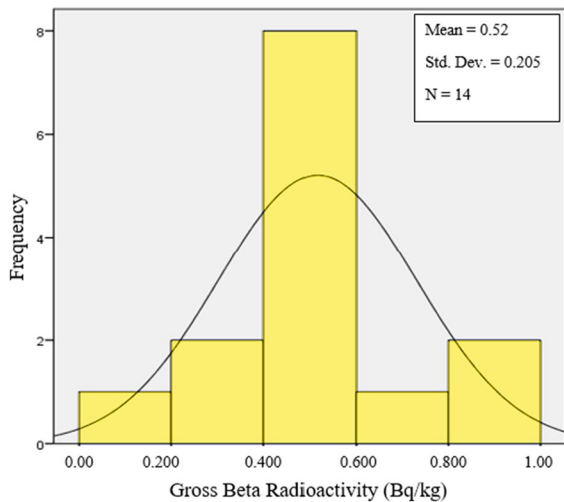


Fig. 3 The frequency distribution of gross beta radioactivity in soil

samples from the province of Kahramanmaraş are 0.25 ± 0.03 Bq/kg and 0.52 ± 0.05 Bq/kg, respectively.

As seen in Table 2; when all of the samples are compared with each other, it is seen that the radioactivity levels of the soil samples Kazma Bağları position with 1 number and the sample Yenişehir neighborhood with 14 number, the sample Gaffarlı neighborhood with 5 number, and the sample Eyüp Sultan neighborhood with 8 number and the sample Oruç Reis neighborhood with 10 number and the sample Hürriyet neighborhood with 12 number and the sample Akif İnan neighborhood with 13 number are remarkable with each other. Gross alpha radioactivity levels of samples are distinct from one another with values of 0.06 ± 0.01 Bq/kg and 0.21 ± 0.02 Bq/kg; however, the beta radioactivity levels of samples with 1 and 14 numbers are quite near to one another with values of 0.56 ± 0.05 Bq/kg and 0.54 ± 0.05 Bq/kg, respectively. Additionally, despite the fact that samples with the numbers 5 and 8 had gross beta radioactivity levels that are quite similar to one another at 0.95 ± 0.09 Bq/kg and 0.92 ± 0.09 Bq/kg, respectively,

The samples' respective gross alpha radioactivity values are 0.41 ± 0.04 Bq/kg and 0.27 ± 0.03 Bq/kg. Additionally, the gross alpha radioactivity levels of the samples with the 10, 12, and 13 numbers are different from one another, with values of 0.17 ± 0.02 Bq/kg, 0.45 ± 0.04 Bq/kg, and

0.22 ± 0.02 Bq/kg, respectively, despite the fact that the samples' gross beta radioactivity levels are very similar to one another with values of 0.43 ± 0.04 Bq/kg, 0.45 ± 0.04 Bq/kg, and 0.44 ± 0.04 Bq/kg, respectively. In addition to the amount of radioactivity in the soils, which varies based on a number of factors, including weather, soil filtration, absorption, sedimentation produced by groundwater movement, degree of porosity, etc., diverse soil structures and rock structures also exist. In Table 1, information is given about the soil structure of the regions where soil samples are taken.

Despite having the same soil structure, samples with the numbers 1, 4, 5, 6, and 11 had different gross alpha and gross beta activity. The underlying rock structure and different soil profiles might both be to blame for this.

When samples with 2, 8, 9, and 10 numbers are examined, the soil structures are the same. Not only did Alivual soils cause the gross alpha radioactivity of the uranium-rich limestone and conglomerate soil sample to be high, but also the alluvial nature of the soil caused the highest gross beta radioactivity to be measured (Liden & Holm, 1985; Hansen & Stout, 1968). Samples with 3, 7, and 13 numbers have the same soil structure. They are at modest levels when measured against the gross alpha and gross beta radioactivities of other soil samples. The reason for this may be that the regions where samples with 3, 7, and 13 numbers were taken are dense with metamorphic marbles and sandy limestone, which are old units. (Valkovic, 2000). The soil structure of samples with 12 and 14 numbers is colluvial soil. Although the gross beta activities are close to each other, the difference in gross alpha activities may be due to the change in the free lime content of the soil structure.

Table 3 lists the gross alpha and beta values for soil samples obtained from the city center of Kahramanmaraş and from other investigations. The gross alpha and beta values in studies by Lee et al. (2014), Bose et al. (1993), Dimovska et al. (2012), Bal et al. (2015), and Canbazoğlu et al. (2012) are significantly higher than the values in our study when the gross alpha and beta values of soil samples taken from Kahramanmaraş city center are compared with those in other studies. However, the values of our study and the study by Chijioke et al., (2018) in Nigeria are in agreement. This may be due to the soil and rock structures in the study

Table 3 Comparison of results for the gross alpha and beta activity concentrations (Bq/kg) in the soil samples from the Kahramanmaraş city center and other studies

Location	Mean gross alpha activity (Bq/kg)	Range (Bq/kg)	Mean gross beta activity (Bq/kg)	Range (Bq/kg)	References
Kinta district, Malaysia	1558	15–9634	112	142–6173	Lee et al., (2014)
Dhaka, Bangladesh	1020	468–1710	635	303–1125	Bose et al.(1993)
Republic of Macedonia	522	221–1360	681	438–1052	Dimovska et al., (2012)
Sivrice,Elazığ, Turkey	471	206–837	267	111–423	Bal et al. (2015)
Elazığ, Turkey	289	126–551	143	59–360	Canbazoğlu et al., (2012)
Nigeria	–	0.35–0.53	–	0.46–1.04	Chijioko (2018)
Kahramanmaraş Turkey	0.25	0.06–0.45	0.52	0.14–0.95	Present study

areas. The reason for the differences in the radioactivity concentration of the soils in other studies may have been due to the weather conditions in the study area. In the same way, it may have differed due to many effects such as sedimentation, filtration, absorption, sedimentation caused by the movement of groundwater, high porosity, etc. In addition to these, it may have differed due to the different soil rock structures.

The activity concentrations of radionuclides (^{238}U , ^{232}Th and ^{40}K) in soil samples

Table 4 lists the activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in 14 soil samples collected from the Kahramanmaraş city center. When Table 4 is studied, the Pnarbaşı neighborhood sample has the lowest concentration of ^{238}U at a value of 2.32 ± 0.2 Bq/kg, and the Gaffarlı neighborhood sample has the greatest concentration at a value of 40.10 ± 1.4 Bq/kg. Besides; the lowest concentration of ^{232}Th is in the Hürriyet neighborhood sample with 0.60 ± 0.03 Bq/kg, and the highest concentration of ^{232}Th is in the Göllü neighborhood sample with 10.47 ± 1.01 Bq/kg. Apart from these, the Oruç Reis neighborhood sample has the lowest ^{40}K concentration (11.60 ± 1.01 Bq/kg), while the Pnarbaşı neighborhood sample has the highest ^{40}K concentration (160.84 ± 4.6 Bq/kg). There are currently 11.50 ± 1.1 , 4.50 ± 0.4 , and 62.20 ± 1.6 Bq/kg, respectively, of ^{238}U , ^{232}Th , and ^{40}K activity concentrations in soil.

Figures 4, 5, and 6 display the frequency distribution of soil's ^{238}U , ^{232}Th , and ^{40}K radioactivity concentrations. In ten samples, the quantity of ^{238}U ranged from 0.00 to 10.00 Bq/kg, as shown in Fig. 4. Figure 5 shows that the concentration of ^{232}Th ranged

from 0.00 to 2.00 Bq/kg in six samples. Figure 6 shows that the content of ^{40}K ranged from 0.00 to 50.00 Bq/kg in eight samples.

The literature reports that the average activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in soil are 25 Bq/kg, 25 Bq/kg, and 370 Bq/kg, respectively, on a global scale (Liden & Holm, 1985). When these values are compared to the mean activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in soil samples taken from the heart of Kahramanmaraş, it is found that the concentrations do not go over these limits. The remaining samples, with the exception of the sample with the number 5, don't appear to surpass these levels for the concentration of ^{238}U . When a sample with five numbers is analyzed, it becomes clear that the ^{40}K activity concentration is also larger than the concentrations in the other samples. This results from the sample with the 5 number also having greater gross alpha and gross beta activity levels than the other samples, that is, the soil structure of this sample (lime-rich claystone potassium-rich) and the rock structure on which it is located (the middle eocene, formed in 38–54 million years, sandstone, mudstone, pebble, spilite, serpentine, limestone, and conglomerate). The main reason why soil samples have a higher concentration of ^{238}U than ^{232}Th concentration is that the samples are taken from a depth of 0–5 cm. In scientific studies, it has been reported that the upper part of the soil has a higher concentration of uranium than thorium (Hansen & Stout, 1968). The fact that the top section of the soil is rich in organic matter is frequently thought to be the cause of the concentrations of ^{238}U and ^{232}Th in soil samples changing in an inverse proportion. This is due to

the fact that uranium’s mobility is less and thorium’s mobility is stronger in soils with a high level of organic matter (Hansen & Huntington, 1969; Schulz, 1965).

Table 5 lists the activity levels of ^{238}U , ^{232}Th , and ^{40}K in soil samples obtained from Kahramanmaraş’s city center and from other investigations. When compared to previous studies, the activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in soil samples from the center of Kahramanmaraş are much greater in research by Baykara & Doğru (2009), Al-Hamarneh and Awadallah (2009), UNSCEAR (2000a), Kova’cs et al., (2013), Tsai et al., (2008), and Hannan et al., (2013). The reason for the differences in the radioactivity concentration of the soils; may have been due to the weather conditions in the study area. In the same way, it may have differed due to many effects such as sedimentation, filtration, absorption, sedimentation caused by the movement of groundwater, high porosity, etc. In addition to these, it may have differed due to the different soil rock structures.

AEDE, ELCR, and terrestrial absorbed gamma dose rate

The computed annual effective dose equivalent (AEDE), excessive lifetime cancer risk (ELCR), and terrestrial absorbed gamma dose rate are all shown in Table 6. Accordingly to this, the terrestrial absorbed gamma dose rate, annual effective dose equivalent (AEDE), and excessive lifetime cancer risk (ELCR)

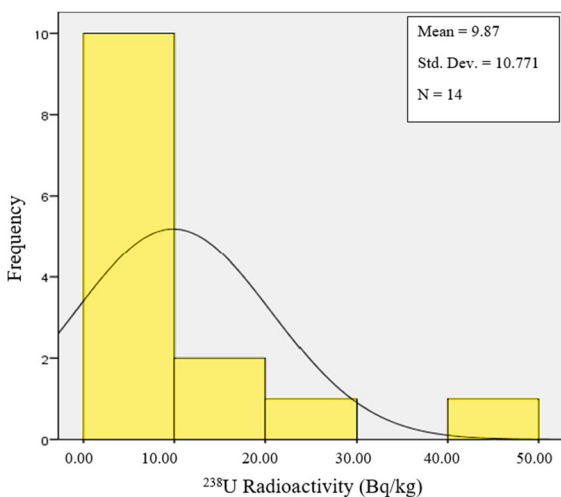


Fig. 4 The frequency distribution of the ^{238}U activity concentration in soil

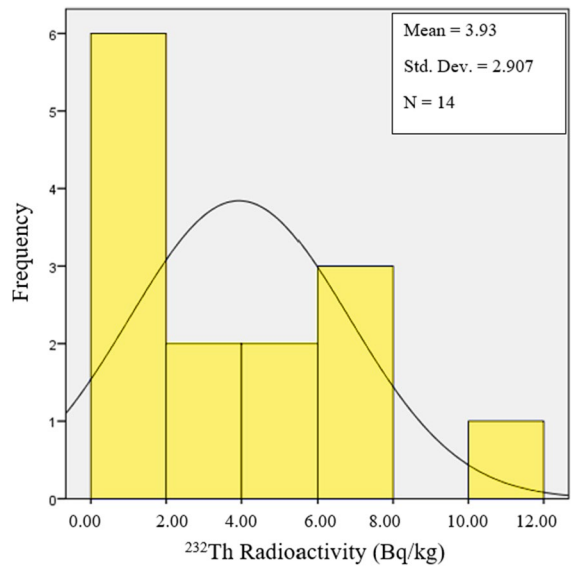


Fig. 5 The frequency distribution of ^{232}Th activity concentration in soil

range from 1.72 ± 0.01 nGy h^{-1} to 25.05 ± 0.21 nGy h^{-1} , 0.01 ± 0.01 $\mu\text{Sv y}^{-1}$ to 0.03 ± 0.02 $\mu\text{Sv y}^{-1}$, and $0.01 \pm 0.01 \times 10^{-3}$ to $0.12 \pm 0.03 \times 10^{-3}$, respectively. In addition, the average terrestrial absorbed gamma dose rate, average annual effective dose equivalent

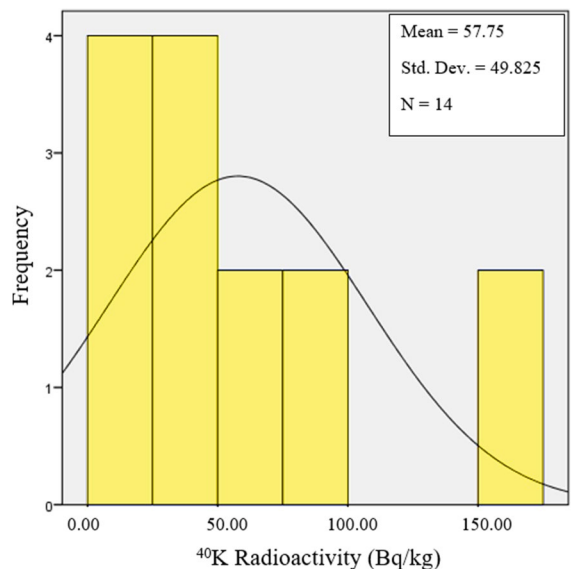


Fig. 6 The frequency distribution of ^{40}K activity concentration in soil

Table 4 The activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in soil samples collected from the Kahramanmaraş city center

Example no	Sample place	Radionuclide concentration (Bq/kg)		
		^{238}U	^{232}Th	^{40}K
1	Kazma Bağları position	4.11 ± 0.4	1.98 ± 0.1	48.95 ± 1.4
2	Bahçelievler neighborhood	UDL	1.32 ± 0.1	19.58 ± 1.09
3	Karamanlı neighborhood	22.77 ± 1.2	6.14 ± 0.6	UDL
4	Barbaros neighborhood	UDL	1.84 ± 0.1	77.70 ± 2.07
5	Gaffarlı neighborhood	40.10 ± 1.4	1.98 ± 0.1	153.85 ± 3.8
6	Yassıpınar position	9.06 ± 0.9	6.61 ± 0.6	69.93 ± 1.6
7	Göllü neighborhood	4.43 ± 0.4	10.47 ± 1.01	34.97 ± 1.3
8	Eyüp Sultan neighborhood	9.06 ± 0.9	0.76 ± 0.7	69.93 ± 1.7
9	Gayberli neighborhood	2.42 ± 0.2	2.65 ± 0.2	27.97 ± 1.02
10	Oruç Reis neighborhood	14.09 ± 1.4	4.41 ± 0.4	11.60 ± 1.01
11	Pınarbaşı neighborhood	2.32 ± 0.2	7.28 ± 0.7	160.84 ± 4.6
12	Hürriyet neighborhood	5.71 ± 0.5	0.60 ± 0.03	12.72 ± 1.01
13	Akif İnan neighborhood	14.49 ± 1.4	3.67 ± 0.01	85.47 ± 2.4
14	Yenişehir neighborhood	9.66 ± 0.9	5.34 ± 0.02	34.97 ± 1.3
Maximum		40.10 ± 1.4	10.47 ± 1.01	160.84 ± 4.6
Minimum		2.32 ± 0.2	0.60 ± 0.03	11.60 ± 1.01
Mean		11.50 ± 1.1	4.50 ± 0.4	62.20 ± 1.6

UDL Under Detection Limit

(AEDE), and average excessive lifetime cancer risk (ELCR) are $9.81 \pm 0.09 \text{ nGy h}^{-1}$, $0.01 \pm 0.01 \text{ } \mu\text{Sv y}^{-1}$, and $0.05 \pm 0.02 \times 10^{-3}$, respectively.

The global average rate of terrestrial gamma radiation absorption is 60 nGy h^{-1} (UNSCEAR, 2000b). The current study's mean terrestrial absorbed gamma radiation rate is lower than the global average value. Outdoor terrestrial gamma radiation has an average annual effective dose equivalent (AEDE) of 70 mSv worldwide (UNSCEAR, 2000b). As a result, the Kahramanmaraş city center's average yearly effective dosage is lower than the global average value. UNSCEAR reports that the average ELCR value throughout the globe is 0.29×10^{-3} (UNSCEAR, 2000b). The average ELCR for the current research is thus lower than the global average value.

Conclusion

With the exception of the ^{238}U concentration of the sample with the number 5, it appears that the other samples do not exceed these values when the activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in soil samples from the Kahramanmaraş city center are compared to

global average activity concentrations values. Additionally, the average excessive lifetime cancer risk (ELCR), average annual effective dose equivalent (AEDE), and average terrestrial absorbed gamma radiation rate in Kahramanmaraş city center are lower than the global average values.

As a result; although the level of natural radioactivity caused by terrestrial radionuclides is low in the city center of Kahramanmaraş, people's living environments and eating habits will determine the dose they will be exposed to. It turns out that it is impossible to escape from natural radiation. However, the fact that we are surrounded by natural radiation does not mean that we are in great danger, and the human body needs natural radiation as well as all the elements in nature. It is in our hands to reduce natural radioactivity levels in the environments we live in. For example, good ventilation in our homes and workplaces reduces the level of radiation we breathe, or filtering drinking water can prevent the radionuclides in the body from being taken into the body. In this regard, the radon gas emissions of our samples should be evaluated in the next few days to determine the amount of natural radioactivity in the Kahramanmaraş city center. In addition, these works should be carried out in

Table 5 Comparison of results for radionuclides activity concentrations (Bq/kg) in the soil samples from the Kahramanmaraş city center and other studies

References	Location	Radionuclide concentration (Bq/kg)		
		²³⁸ U	²³² Th	⁴⁰ K
Baykara and Doğru (2009)	NAFS, Turkey	89	69	626
Al-Hamarneh and Awadallah (2009)	Jordan	49	27	291
UNSCEAR (2000b)	Malaysia	66	82	310
Kovačcs et al., (2013)	Slovenia	63	77	800
Tsai et al., (2008)	Taiwan	24	26	436
Hannan et al., (2013)	USA (Texas)	23	31	300
Present study	Turkey	11.50	4.50	62.20

Table 6 Radiation parameters calculated from Kahramanmaraş city center

Example no	Sample place	Radiation parameters		
		D (nGy h ⁻¹)	AEDE (μSv y ⁻¹)	ELCRx10 ⁻³
1	Kazma Bağları position	5.17 ± 0.05	0.01 ± 0.01	0.03 ± 0.01
2	Bahçelievler neighborhood	1.72 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
3	Karamanlı neighborhood	13.79 ± 0.12	0.02 ± 0.01	0.07 ± 0.02
4	Barbaros neighborhood	4.56 ± 0.04	0.01 ± 0.01	0.02 ± 0.01
5	Gaffarlı neighborhood	25.05 ± 0.21	0.03 ± 0.02	0.12 ± 0.03
6	Yassıpınar position	11.25 ± 0.1	0.01 ± 0.01	0.06 ± 0.02
7	Göllü neighborhood	10.33 ± 0.1	0.01 ± 0.01	0.05 ± 0.02
8	Eyüp Sultan neighborhood	7.38 ± 0.07	0.01 ± 0.01	0.04 ± 0.01
9	Gayberli neighborhood	3.99 ± 0.03	0.01 ± 0.01	0.02 ± 0.01
10	Oruç Reis neighborhood	9.44 ± 0.09	0.01 ± 0.01	0.05 ± 0.01
11	Pınarbaşı neighborhood	12.72 ± 0.1	0.02 ± 0.01	0.06 ± 0.02
12	Hürriyet neighborhood	3.38 ± 0.03	0.01 ± 0.01	0.02 ± 0.01
13	Akif İnan neighborhood	12.30 ± 0.1	0.02 ± 0.01	0.06 ± 0.02
14	Yenişehir neighborhood	9.17 ± 0.09	0.01 ± 0.01	0.05 ± 0.01
	Maximum	25.05 ± 0.21	0.03 ± 0.02	0.12 ± 0.03
	Minimum	1.72 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
	Mean	9.81 ± 0.09	0.01 ± 0.01	0.05 ± 0.02

D Terrestrial absorbed gamma dose rate
AEDE Annual Effective Dose Equivalent
ELCR Lifetime Cancer Risk

the city center of Kahramanmaraş, in the local well waters used as drinking and utility water, and in the dam lakes that provide aquaculture products to the city. With this study, the natural radiation level of the Kahramanmaraş city center, which had not been done before, is determined. Thus, these study results can be used as a reference value for future differences.

Acknowledgements We would like to thank Doç. Dr. Sultan Şahin Bal, Doç. Dr. Şule Karatepe Çelik for support.

Author contributions Study conception, design, and data collection are done by Erdal Küçükönder and Serdar Gümbür. Serdar Gümbür wrote the main manuscript text and prepared

figures. Ömer Söğüt and Mahmut Doğru helped analyze and interpret of results, and all authors reviewed the manuscript.

Funding This research was not supported by any organization.

Data availability The corresponding author can provide you with the information needed to access the data that support this study’s conclusions.

Declarations

Conflict of interest The authors state that they have no interest in conflict. All authors have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors.

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