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Determination of Radioactivity Levels in Soil Samples of Recep Tayyip Erdogan University Campus in Rize Province

Esra YILMAZ BAYRAK[1*], Hasan BALTAŞ[2]

[1]Gumushane University, Torul Vocational School, Department of Medical Services and Techniques, 29800, Torul/Gümüşhane, Türkiye
[2]Recep Tayyip Erdogan University, Faculty of Arts and Science, Department of Physics, 53100 Rize, Türkiye

[*]Sorumlu Yazar/Corresponding Author
E-mail: esrayilmaz.bayrak@gumushane.edu.tr

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ABSTRACT

Recep Tayyip Erdogan University Zihni Derin Campus, situated at the Eastern Black Sea Region of Turkey, in the province of Rize, was established on a land area of approximately 3.254.430.28 m². It was found that tea, which was thought to be affected by radiation after the nuclear accident at the Chernobyl Nuclear Power Plant, was buried in sacks in this area, which was used as a tea factory before. Therefore, it is crucial to determine the radiation levels in the campus area. In this study, the quantities of artificial (^{137}Cs), and natural (^{226}Ra, ^{232}Th, and ^{40}K) radionuclides, were assessed using a high purity germanium detector (HPGe) in 15 soil samples collected from the Zihni Derin Campus of Recep Tayyip Erdogan University in Rize. For ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs the activity values of soil samples varied from 43.78 to 62.58, 29.85 to 41.61, 132.48 to 346.44 and 3.90 to 202.94 Bq kg^{-1}, respectively. Upon comparison with the average global values provided by the UNSCEAR (2000), it was observed that the mean activity values for ^{226}Ra and ^{232}Th in the soil samples were higher. Conversely, the average activity concentrations for ^{40}K and ^{137}Cs were found to be lower than the world average values reported by UNSCEAR (2000). Furthermore, radiological hazard indexes were calculated and compared with internationally acceptable values. This research demonstrates that there are no health concerns for individuals exposed to the soil samples in the study area.

Keywords: Lifetime cancer risk, Radioactivity, Radiological hazard indices, Recep Tayyip Erdogan University, Soil

Rize İli Recep Tayyip Erdoğan Üniversitesi Yerleşkesi Toprak Örneklerinde Radyoaktivite Düzeylerinin Belirlenmesi

ÖZ

Türkiye'nin Doğu Karadeniz Bölgesi Rize ilinde bulunan Recep Tayyip Erdoğan Üniversitesi Zihni Derin Yerleşkesi yaklaşık 3.254.430.28 m² lik bir alana kurulmuştur. Daha önce çay fabrikası olarak kullanılan bu alana, Çernobil Nükleer Santrali'nde meydana gelen nükleer kaza sonrası radyasyondan etkilendiği düşünülen çayların çuvallarla gömüldüğü tespit edilmiştir. Dolayısıyla bu kampüs alanında radyasyon seviyelerinin belirlenmesi önem arz etmektedir. Bu yüzden bu çalışmada, Rize ili Recep Tayyip Erdoğan Üniversitesi Zihni Derin Yerleşkesinden alınan 15 adet toprak örneğinde yüksek saflıkta bir germanyum dedektörü (HPGe) kullanılarak yapay (^{137}Cs) ve doğal (^{226}Ra, ^{232}Th and ^{40}K) radyonüklidlerin miktarları belirlenmiştir. ^{226}Ra, ^{232}Th, ^{40}K ve ^{137}Cs için toprak numunelerinin aktivite değerleri sırasıyla 43.78 ile 62.58, 29.85 ile 41.61, 132.48 ile 346.44 ve 3.90 ile 202.94 Bq kg^{-1} arasında değişmiştir. UNSCEAR (2000) tarafından verilen dünya ortalama değerleri ile karşılaştırıldığında, toprak numuneleri için ortalama ^{226}Ra, ^{232}Th aktivite değerlerinin daha yüksek olduğu fark edilmiştir. ^{40}K ve ^{137}C için ise ortalama aktivite konsantrasyonlarının, UNSCEAR (2000) tarafından bildirilen dünya ortalama değerlerinden daha düşük olduğu gözlemlenmiştir. Bunun yanı sıra radyolojik tehlike indeksleri hesaplanarak bu indeksler uluslararası izin verilen değerlerle karşılaştırılmıştır. Yapılan bu araştırma, çalışma alanında toprak örneklerine maruz kalanlar açısından herhangi bir sağlık sorunu olmadığını göstermiştir.

Anahtar Kelimeler: Yaşam boyu kanser riski, Radyoaktivite, Radyolojik tehlike indeksleri, Recep Tayyip Erdoğan Üniversitesi, Toprak

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1. Introduction

Human beings have always had to live with radiation since its existence. Long-lived radioactive nuclei that emerged in nature with the creation of the world have created a natural radiation concentration that is accepted as unavoidable in the atmosphere we live in. Natural and unnatural radionuclides are two major environmental radiation in the environment, which are the main sources of human exposure to radiation. Primordial radionuclides, particularly ^{238}U, ^{232}Th and their byproducts, and ^{40}K, account for a significant portion of the natural sources (Celik et al., 2009). It also comes from cosmic rays from the **s**un, cosmic rays from stars, and radioisotopes in the earth's crust, hence from natural sources such as soil and building materials, water, and food (Damla et al., 2011). As natural ecological radioactivity varies on geographical factors, the amount of gamma exposure varies for various soil types around the World (Tzortzis et al., 2003). Information on total gamma-ray dose rates can be found in gamma ray data (Appleton and Kendall, 2022). Radionuclide distribution and radiation levels determined for the environment are of great importance to evaluate the effects of each of the geological, cosmological and terrestrial sources on the radiation exposure.

In addition to its contributions to the total dose, measurement of the external gamma dose from terrestrial sources is required due to variations in the individual dose associated with the process. These doses are strongly dependent on the levels of ^{238}U, ^{232}Th, their progenies, and also ^{40}K found in rocks and soil, depend on the geology of the regions. (Ahmad et al., 2015).

It is not possible to prevent the radiation emitted by the natural radioactive elements in our soil and atmosphere. Soil contain varying level of radiation due to some radioactive elements in the main material that forms them. It is a known phenomenon that these elements dissolve in water and pass to water resources and plants thus are transferred to human (Bakaç and Kumru, 1999). Therefore, soil and soil-derived geological materials containing natural radiation are the cause of radiation exposure of people in the environment. Therefore, it is necessary to determine the effects of the radiation emitted by these soil and soil-derived substances on living organisms, especially human.

Everal radionuclides of artificial origins, in addition to the natural radionuclides ^{238}Ra, ^{232}Th, and ^{40}K, are released to the environment through a variety of processes. One of them is the element ^{137}Cs. Physical half-life for the element ^{137}Cs is 30 years (IAEA, 1995). The ^{137}Cs activity concentration in the surface soil of the eastern Black Sea Mountains was reported between 4000 and 4500 Bq kg^{-1} in 0.5 cm soil in 1988 by the Çekmece Nuclear Research and Education Center (ÇANEM) (Unlu et al., 1995). As a result of the Chernobyl accident, Rize Province is among those in Eastern Turkey's Black Sea region with the highest levels of ground pollution.

In this study, soil samples were collected from the area surrounding the Recep Tayyip Erdogan University Zihni Derin Campus in Rize Province. The concentrations of natural ^{238}Ra, ^{232}Th, and ^{40}K as well as unnatural ^{137}Cs were recorded using an HPGe device. Besides, radiological hazard indices (D, Ra_{eq}, H_{ex}, AGDE, AEDE and ELCR) were calculated.

2. Material and Method

2.1. Study Area and Sampling

This study was carried out in the Zihni Derin Campus of Recep Tayyip Erdogan University, located in Rize in the Black Sea Region of Turkey. The campus area is located at 41°2'12"N latitudes and 40°29'39"E longitudes and its surface area is 3.254.430.28 m². It is known that, this Campus was established in 1947 as the Zihni Derin Tea Factory, but was demolished in 1999 in order to establish a university in its place (Figure 1).

In total, 15 random soil samples were collected from various spots on the Recep Tayyip Erdogan University grounds. Due to the mixing of various layers caused by geological and/or human activities, in situ soil is not homogeneous

(Roberto et al., 2015). For this reason, a composite soil sample of approximately 2 kg was obtained at each sampling location (about 100 ×100 m) by combining four surface-collected sub-samples (Baltas et al., 2022). Using a crushing device, the materials were granulated, homogenized, and sieved to a mesh size of about 100. Samples were dried for 24 hours at 70°C in a temperature-controlled oven so as to remove moisture. Each sample was put into a cylinder-shaped, radon-impermeable, gas-tight polyethylene receptacle, and allowed to stabilize for 30 days (Celik et al., 2010).

Figure 1. The sampling sites on the Zihni Derin Campus of Recep Tayyip Erdogan University

2.2. Gamma Spectrometry Measurement

Using a coaxial HPGe detector with a 55% relative efficiency and 1.9 keV accuracy 1332 keV gamma radiation at the ^{60}Co, gamma spectrometry measurements were performed for all samples (Ortec, GEM55P4-95 model). The device was protected by a lead well that was 10 centimeters thick and had 2 mm Cu foils inside of it. The computer program Genie 2000, which was purchased from CANBERRA, was used to conduct the spectrum study.

The ^{226}Ra series is characterized by gamma energy levels of 351.9 keV (^{214}Pb) and 609.3 keV (^{214}Bi), while the ^{232}Th series is represented by energy levels of 911.1 keV (^{228}Ac) and 583.1 keV (^{208}Tl). Applying gamma lines at 1460.8 keV, ^{40}K was studied (Baltas et al., 2018; Cevik et al., 2006; Kucukomeroglu et al., 2011). The following equation was used to calculate the activity values of the ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in the analyzed samples:

$$A = \frac{s}{(I_\gamma).w.t.\varepsilon} \quad \textbf{(1)}$$

Where, A (Bq kg^{-1}) is the activity, s is the net field of the total absorption line, Iγ is the absolute intensity of the transition, w is the mass of the sample, t is the sample measurement period and ε is the full energy peak capacity.

The equation shown below was used to calculate the MDA of the current gamma system (Curie, 1968):

$$MDA = \frac{\sigma\sqrt{B}}{\varepsilon.I_\gamma.t.w} \quad \textbf{(2)}$$

Where MDA is expressed in Bq kg^{-1}, is a statistical coverage factor equivalent to 1.645 (95% confidence level), and B is the background value of a radionuclide. (Baltas et al., 2018).

According to calculations, the MDA for the radionuclides under study ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs was 0.16, 0.24, 1.69 and 0.02 Bq kg^{-1}, respectively. To check the accuracy of the measuring system, a sample of the certified reference substance IAEA-447 was measured in triplicated forma on the instrument. Concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the reference sample are given as 25.04, 37.3, 550 and 371.11 Bq kg^{-1}, respectively. The values of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs for the measurement method were determined 23.96, 35.7, 521 and 362.55 Bq kg^{-1}, respectively. Accuracy for all radionuclides was between 95 and 98 percent of reference material (Şirin, 2019).

3. Results and Discussion

3.1. Natural radioactivity in soil (^{226}Ra, ^{232}Th and ^{40}K)

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides detected in soil samples taken from 15 locations from the Recep Tayyip Erdogan University Zihni Derin Campus area are shown in Table 1.

The concentrations found in the present research were between the range of 43.78 to 62.58 Bq kg^{-1} (mean concentration 50.06 Bq kg^{-1}) for ^{226}Ra, 29.85 to 41.61 Bq kg^{-1} (mean concentration 34.91 Bq kg^{-1}) for ^{232}Th and 132.48 to 346.44 (mean concentration 199.70 Bq kg^{-1}) for ^{40}K. Also, the highest ^{226}Ra was observed in the C-13, while the highest ^{232}Th concentration was observed in C-15 and the highest ^{40}K concentration was observed in C-6.

Additionally, Table 2 compares the typical activity concentrations in the soil samples from this research with the findings from the literature. When ^{226}Ra concentrations are compared, it is clear that, this research has the highest value in Ordu (Celik et al., 2010) and Kars (Cengiz B., 2017) provinces have reported ^{232}Th activity concentrations that are greater than present study, but other provinces do not. Our values are lower than the ^{40}K values found in previous studies.

It was observed that the mean ^{226}Ra and ^{232}Th concentration values in the all samples were higher than the values recommended by UNSCEAR (2000) and the ^{40}K concentrations were lower than the recommended values.

3.2. Artificial Radioactivity in Soil (^{137}Cs)

The concentrations of ^{137}Cs activity detected in this research are shown in Table 1. The activity concentrations of ^{137}Cs in soil samples was 3.90 to 202.94 Bq kg^{-1} (with a mean value of 43.47 Bq kg^{-1}). Comparing the activity concentrations shows that C-8 has the greatest concentration (202.94 Bq kg^{-1}), while C-1 has the lowest (3.90 Bq kg^{-1}). Additionally, in Table 2, the findings of this research are compared with findings from many other studies that have been published in the literature. As shown in Table 2, when ^{137}Cs concentrations are compared, it is seen that ^{137}Cs concentrations at all stations except Artvin (Celik et al., 2009) and Ordu (Celik, 2010) provinces are lower than the mean concentration in this research.

When the previous studies conducted in this region are examined, it is hypothesized that the elevated Cs values observed in Artvin and Ordu provinces are associated with the Chernobyl Nuclear Accident that occurred in 1986 (Çelik et al., 2009; Çelik et al., 2010). The Chernobyl Nuclear Accident, which happened in 1986, had a significant impact on the Eastern Black Sea Region, thus studies have shown higher radiation pollution levels. Therefore, it is believed that the region impacted by this disaster is to fault for the high ^{137}Cs concentration in C-8 (Celik et al., 2019; Celik et al., 2010; Baltas et al., 2017).

3.3. Statistical analysis

Classical statistics were calculated using SPSS software. The frequency distributions of ^{226}Ra, ^{232}Th, ^{40}K ^{137}Cs for the collected samples are shown in Figure 2, and taking into account the skewness and kurtosis coefficients, which show whether there is a distribution or not, the harmony between them is drawn. Variables obey the normal or lognormal law. The existence of a normal distribution is inferred from the fact that the skewness and kurtosis indexes, which are determined by dividing the skewness and kurtosis values by their standard errors (±), are near to zero within the bounds of ±2. The activity distributions of the naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil samples are essentially normal (Figure 2). The frequency distribution of natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K in soil samples has skewness and kurtosis values of 1.1141±1.92, 1.872±1.67, 0.463±0.79; -1.000±0.89, and 1.575±2.71, 2.337±2.08 respectively. The same coefficients are respectively 2.358±3.43 and 6.031±4.52, for the distribution of ^{137}Cs in soil. It was discovered that the ranges of ^{137}Cs activity values in soil samples have an abnormal shape (Figure 2).

Table 1. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil samples of Recep Tayyip Erdogan University Zihni Derin Campus

Sampling location	**^{226}Ra (Bq kg^{-1})**	**^{232}Th (Bq kg^{-1})**	**^{40}K (Bq kg^{-1})**	**^{137}Cs (Bq kg^{-1})**
C-1	52.78± 2.69	36.88±1.73	168.04±9.89	3.90±0.51
C-2	54.02±2.43	31.21±1.60	160.07±9.96	33.35±1.19
C-3	50.05±3.16	34.97±1.95	198.4±12.22	22.10±1.14
C-4	43.78±2.55	40.60±1.92	211.9±11.33	68.35±1.68
C-5	44.74±2.62	32.16±1.68	165.2±10.06	15.80±0.87
C-6	50.30±2.53	30.98±1.68	346.4±12.83	4.92±0.57
C-7	48.54±2.71	31.40±1.64	170.76±10.18	-
C-8	45.19±2.54	29.85±1.64	203.87±11.03	202.94±2.72
C-9	48.65±2.79	30.65±1.64	171.75±10.52	66.70±1.65
C-10	52.12±2.76	35.56±1.71	277.38±12.34	-
C-11	46.69±2.67	36.35±1.68	132.48±9.52	-
C-12	55.06±2.74	33.82±1.61	185.87±10.64	7.84±0.62
C-13	62.58±2.81	41.10±1.67	164.83±9.18	-
C-14	50.30±2.54	36.67±1.68	264.40±11.24	-
C-15	46.17±2.54	41.61±1.80	174.04±9.78	8.77±0.68
Min	**43.78**	**29.85**	**132.48**	**3.90**
Max	**62.58**	**41.61**	**346.44**	**202.94**
Mean	**50.06**	**34.91**	**199.70**	**43.47**

Table 2. Comparison of the present study's average activity (Bq kg^{-1}) concentrations in soil samples with data from published studies.

Location	**^{226}R**	**^{232}Th**	**^{40}K**	**^{137}Cs**	**Referance**
Turkey (Rize)	-	14	404	41	Duran et al. (2019)
Turkey (Trabzon)	-	7	224	5	Kuçukomeroglu et al. (2016)
Turkey (Artvin)	49.78	33.6	630.78	80.01	Celik et al. (2009)
Turkey (Ordu)	58.64	46.11	580.91	136.12	Celik et al. (2010)
Turkey (Sakarya)	23.2	21	371	-	Kuş (2017)
Turkey (İstanbul Islands)	-	19.3	429.5	8.9	Hafızoğlu et al. (2020)
Turkey (Kilis)	16.0	15.0	206.0	9.5	Canbazoğlu et al. (2013)
Turkey (Şanlıurfa)	20.8	24.9	298.6	9.1	Bozkurt et al. (2007)
Japan	26.4	14.8	581.0	24.5	Chikasawa et al. (2001)
Georgia	24.0	26.9	464.0	21.7	Kekelidze et al. (2017)
Turkey (Kars)	19.9	57.9	562.0	6.1	Cengiz (2017)
UNSCEAR	35	30	400	-	UNSCEAR (2000)
Recep Tayyip Erdogan University (Rize)	**50.06**	**34.91**	**199.70**	**43.47**	**This Study**

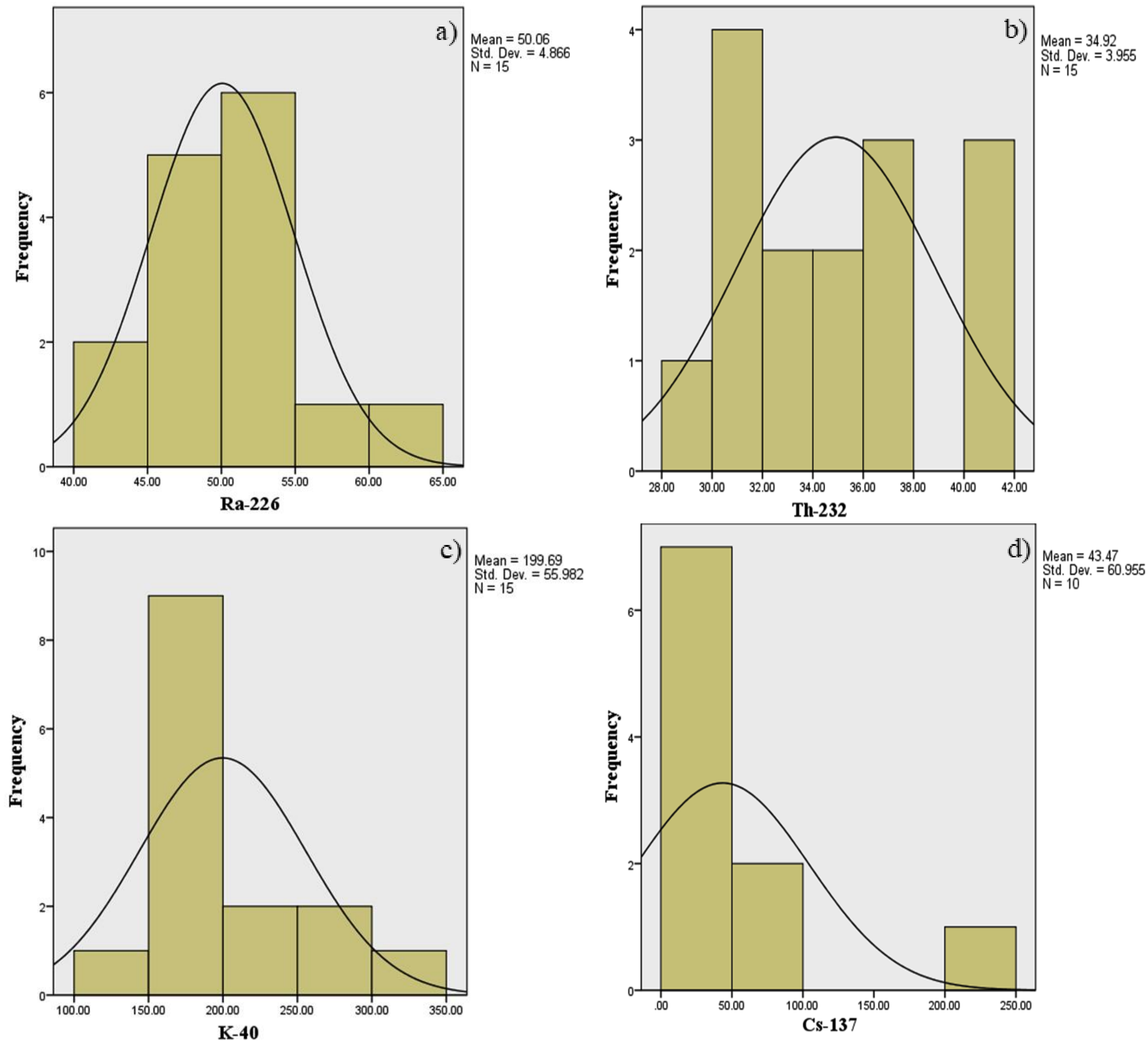

Figure 2. Frequency distributions of radionuclides for samples such as a)^{226}Ra b)^{232}Th c)^{40}K d)^{137}Cs

3.4. Radiological Hazard Indices

3.4.1. Absorbed Dose Rate in Air (D)

The amount of radionuclides that contribute relies on the rate at which airborne doses are absorbed as well as the concentration of radionuclides with naturally occurring specific activity, such as ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs. Terrestrial radionuclides make up the majority of gamma energy. Terrestrial gamma radiation and radionuclide levels are directly correlated. If the radionuclide activity is well known, the gamma dose rate for outdoor exposure at 1 meter above the surface can be determined using the formulas of Beck (1972) and UNSCEAR (2000).

$$D(nGy/h) = 0.427.A_{Ra} + 0.662.A_{Th} + 0.0432.A_K + 0.1243.A_{Cs} \quad \textbf{(3)}$$

where A_{Ra}, A_{Th}, A_K and A_{Cs} are the activity concentrations (in Bq kg^{-1}) of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, respectively, in the soil samples. The dose conversion factors used to transform the detected concentrations into doses were 0. 427, 0.662, 0.432 and 0.1243 nGyh^{-1}, respectively (Beck, 1972; Kurnaz et al., 2007). Table 3 shows that the soil sample absorbed gamma dose rates varied from 52.15 to 76.70 nGyh^{-1}, with a mean value of 60.28 nGyh^{-1}. The calculated mean doses are less than the worldwide standard of 60 nGyh^{-1} for all samples (Kayakökü and Doğru, 2017).

3.4.2. Radium Equivalent Activity (Ra_{eq})

Radium Equivalent Activity (Ra_{eq}), is often used in the risk index. It is calculated by means of the equation given by Beretka and Matthew (1985);

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad \textbf{(4)}$$

A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}), respectively. Table 3 displays the findings of radium equivalent activities (Ra_{eq}) for soil. As shown in Table 3, the mean Ra_{eq} value was 121.89 Bq kg^{-1}, with a range of 108.89 Bq kg^{-1} to 143.28 Bq kg^{-1}. It was noted that the calculated average value fell below the 370 Bq kg^{-1} permissible value **(**Beretka and Matthew, 1985).

3.4.3. External Hazard Index (H_{ex})

This index's primary goal is to keep radiation exposure below the 1 $mSvy^{-1}$ dose equivalent limit. To ensure that the amount of radiation risk is minimal, H_{ex} should not exceed the unity limit. The formula listed below was used to calculate H_{ex} (Suresh et al., 2014).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \textbf{(5)}$$

Where, A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}), respectively. According to Table 3, the external hazard index (H_{ex}), which was computed for each sample, ranged in value from 0.29 to 0.34. Avarage hazar index was 0.37. These values were less than unity.

3.4.4. Annual gonadal dose equivalent (AGDE)

Organs studied by UNSCEAR (2000) include lungs, gonads, thyroid, female breast, bone marrow and bone surface cell. So AGDE can be given as (Mamont-Ciesla et al., 1982):

$$AGDE\ (\mu Sv\ y^{-1}) = 3.09A_{Ra} + 4.18\ A_{Th} + 0.314\ A_K \quad \textbf{(6)}$$

The calculated values of AGDE are showed in Tables 3. The values varied from 338.39 to 440.34 mSv y^{-1} and the mean value was 379.88 µSv y^{-1}.

3.4.5. Annual effective dose equivalent (AEDE)

To calculate the annual effective dose, it is necessary to take into account the conversion coefficient from the dose absorbed in the air to the effective dose and the occupancy factor for both indoor and outdoor spaces. The dose rate obtained from natural radionuclides was calculated by UNSCEAR (2000) as 0.7 Sv $Gyear^{-1}$. People in Turkey spend most of their time indoors. Considering this situation, the following formula was used to calculate the effective dose rate in units of Sv y^{-1} (Celik et al., 2010):

$$AEDE\ (\mu Svy^{-1}) = D(nGyh^{-1}) \times 876\ (hy^{-1}) \times 0.7\ (SvGy^{-1}) \times 0.2 \times 10^{-3} \quad \textbf{(7)}$$

When Table 3 is examined, the annual gonadal dose equivalents determined for soil samples vary between 59.83 and 78.07 μSvy^{-1}, and the average value is 67.08 μSvy^{-1}. However, the average values determined for samples are below the permissible limit value of 80 µSv y^{-1} (ICRP, 1991).

3.4.6. Excess lifetime cancer risk (ELCR)

ELCR values were calculated using equation (8) given below (ICRP, 1991):

$$ELCR = AEDE \times DL \times RF \quad \textbf{(8)}$$

DL, average lifespan (approximately 78 years for Turkey) (Beck, 1972) and RF are factors that indicate the probability of fatal carcinogens (Sv^{-1}) per sievert. Due to some variable effects, the ICRP 60 considers 0.05 for the population (ICRP, 1991). The ELCR values in Table 3 are between 0.23 x 10^{-3}-0.30 x 10^{-3} (mean value 0.26 ± 10^{-3}). When the mean ELCR value was examined, it was found to be lower than the world standards (0.29 10^{-3}) (Taşkın et al., 2009).

Table 3. Radiological hazard indices of the soil samples collected from the Recep Tayyip Erdogan University Zihni Derin Campus.

Sampling location	D (nGy h^{-1})	Ra$_{eq}$ (Bq kg^{-1})	H$_{ex}$	AEDE (μSv y^{-1})	AGDE (μSv y^{-1})	ELCR (x10^{-3})
C-1	58.43±2.92	125.29±6.42	0.34	68.59±3.52	387.34±19.95	0.27
C-2	60.15±3.01	120.78±6.43	0.33	65.88±3.52	372.50±19.94	0.26
C-3	59.37±2.97	121.80±7.41	0.33	67.02±4.07	379.48±23.07	0.26
C-4	63.97±3.20	119.51±6.44	0.32	66.26±3.56	374.96±20.15	0.26
C-5	52.46±2.62	108.89±6,20	0.29	59.83±3.41	338.39±19.30	0.23
C-6	62.10±3.11	129.58±6.29	0.35	72.53±3.48	414.76±19.80	0.28
C-7	52.92±2.65	113.96±6.30	0.31	62.48±3.46	353.54±19.59	0.24
C-8	76.70±3.84	110.17±6.12	0.30	60.81±3.37	345.15±19.15	0.24
C-9	61.00±3.05	113.44±6.44	0.31	62.19±3.53	352.00±20.03	0.24
C-10	61.67±3.06	131.45±6.61	0.36	72.94±3.64	414.84±20.70	0.28
C-11	52.15±2.61	113.32±6.23	0.31	61.96±3.42	349.08±19.34	0.24
C-12	59.89±2.99	126.87±6.35	0.34	69.45±3.49	393.02±19.77	0.27
C-13	66.10±3.31	143.28±6.40	0.39	78.07±3.50	440.34±19.79	0.30
C-14	60.38±3.02	128.96±6.18	0.35	71.56±3.41	406.59±19.34	0.28
C-15	56.94±2.85	121.03±6.19	0.33	66.68±3.40	376.21±19.25	0.26
Min	**52.15**	**108.89**	**0.29**	**59.83**	**338.39**	**0.23**
Max	**76.70**	**143.28**	**0.34**	**78.07**	**440.34**	**0.30**
Mean	**60.28**	**121.89**	**0.37**	**67.08**	**379.88**	**0.26**

4. Conclusions

^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs activities were determined using gamma ray spectroscopy in all samples collected from Recep Tayyip Erdogan University Zihni Derin Campus. It was revealed that the mean activity values of the ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were 50.06 Bq kg^{-1}, 34.91 Bq kg^{-1}, 199.70 Bq kg^{-1} and 43.47 Bq kg^{-1}, respectively. It was observed that, ^{226}Ra and ^{232}Th concentrations were higher than the values suggested by UNSCEAR (2000), whereas ^{40}K values were lower than the suggested values. Additionally, the findings of previous studies published in the literature are lower than the mean concentration level of ^{137}Cs. Morever, compared to some of the past studies published in the literature, this study's mean activity concentration of ^{137}Cs was higher. The results of determining and comparing the radiological hazard indices (D, Ra$_{eq}$, H$_{ex}$, AGDE, AEDE, and ELCR) with worldwide permissible values were also lower than the limit values. The tracking of the Rize's radioactive pollution in the future may therefore benefit from the use of the current data.

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Author Contributions

E.Y. Bayrak: Data Analysis, Visualization, Writing; **H. Baltaş:** Validation, Review and Editing

References

Ahmad, N., Jaafar, S.M., Bakhash, M., Rahim M. (2015). An overview on measurements of natural radioactivity in Malaysia. *Journal of Radiation Research and Applied Sciences*, 8, 136-141. https://doi.org/10.1016/j.jrras.2014.12.008

Appleton, J.D., Kendall, G.M. (2022). Gamma-radiation levels outdoors in Great Britain based on K, Th and U geochemical data. *Journal of Environmental Radioactivity*, 251-252, 1-9. https://doi.org/10.1016/j.jenvrad.2022.106948

Bakaç, M., Kumru, M.N. (1999). Gediz havzası topraklarındaki doğal radyoaktivite seviyesi, *Çev-Kor Vakfı Ekoloji Dergisi*, 8, 18-21.

Baltas, H., Kiris, E., Dalgic, G., Cevik, U. (2016). Distribution of ^{137}Cs in the Mediterranean mussel (*Mytilus galloprovincialis*) in Eastern Black Sea Coast of Turkey. *Marine Pollution Bullettin*, 107, 402–407. https://doi.org/10.1016/j.marpolbul.2016.03.032.

Baltas, H., Kiriş, E., Sirin, M. (2017). Determination of radioactivity levels and heavy metal concentrations in seawater, sediment and anchovy (*Engraulis encrasicolus*) from the Black Sea in Rize, Turkey. *Marine Pollution Bulletin*, 116, 528-533. https://doi.org/10.1016/j.marpolbul.2017.01.016

Baltaş, H., Şirin, M., Dalgıç, G., Çevik, U. (2018). An overview of the ecological half-life of the ^{137}Cs radioisotope and a determination of radioactivity levels in sediment samples after Chernobyl in the Eastern Black Sea, Turkey. *Journal of Marine Systems*, 177, 21–27. https://doi.org/10.1016/j.jmarsys.2017.09.005

Baltas, H., Sirin, M., Gokbayrak, E., Ozcelik, A.E. (2020). A case study on pollution and a human health risk assessment of heavy metals in agricultural soils around Sinop province, Turkey. *Chemosphere,* 241, 1-9. https://doi.org/10.1016/j.chemosphere.2019.125015

Beck, H.L. (1972). The physics of environmental radiation fields. *Natural radiation environment II, CONF-720805 P2, Proceedings of the Second International Symposium on the Natural Radiation Environment* (p. 101-133), 07.08.1972, Houston, Texas, USA.

Beretka, J., Matthew, P.J. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Physics*, 48, 87–95.

Bozkurt, A., Yorulmaz, N., Kam, E., Karahan, G., Osmanlioglu, A.E. (2007). Assessment of environmental radioactivity for Sanliurfa region of southeastern Turkey. *Radiation Measurements*, 42, 1387–1391. https://doi.org/10.1016/j.radmeas.2007.05.052

Canbazoğlu, C., Turhan, Ş., Bakkal, A., Uğur, F.A., Gören, E. (2013). Analysis of gamma emitting radionuclides (terrestrial and anthropogenic) in soil samples from Kilis province in south Anatolia, Turkey. *Annals of Nuclear Energy*, 62, 153-157. http://dx.doi.org/10.1016/j.anucene.2013.05.040.

Cengiz, G.B. (2017). Selim ilçesinin toprak örneklerinde doğal radyoaktivite düzeyleri ve radyolojik etkilerinin değerlendirilmesi. *Kafkas Üniversitesi Fen Bilimleri Enstitüsü Dergisi* 10(1), 37-47.

Celik, N., Cevik, U., Celik, A., Koz, B. (2009). Natural and artificial radioactivity measurements in Eastern Black Sea region of Turkey. *Journal of Hazardous Materials*, 162, 146–153. https://doi.org/10.1016/j.jhazmat.2008.05.017

Celik, N., Damla, N., Cevik, U. (2010). Gamma ray concentrations in soil and building materials in Ordu. *Radiation Effects & Defects in Solids: Incorporating Plasma Science & Plasma Technology*, 165, 1-10. https://doi.org/10.1080/10420150903173270

Cevik, U., Damla, N., Karahan, G., Çelebi, N., Kobya, A.İ. (2006). Natural radioactivity in tap waters of Eastern Black Sea region of Turkey. *Radiation Protection Dosimetry*, 118, 88-92. https://doi.org/10.1093/rpd/nci325

Chikasawa, K., Ishii, T., Sugiyama, H. (2001). Terrestrial gamma radiation in Kochi Prefecture, Japan. *Journal of Health Science*, 47(4), 362–372.

Damla, N., Cevik, U., Kobya, A.I., Celik, A., Celik, N., Yıldırım I. (2011). Assessment of natural radioactivity and mass attenuation coefficients of brick and roofing tile used in Turkey. *Radiation Measurements*, 46, 701-708. https://doi.org/10.1016/j.radmeas.2011.06.004

Duran, S.U., Küçükömeroğlu, B., Çiriş, A., Çelik, N. (2019). Radioactivity levels in soil and drinking water samples collected from Andon Region (Rize Province, Turkey). *Karadeniz Fen Bilimleri Dergisi*, 9(2), 253-263, https://doi.org/10.31466/kfbd.582464

Hafızoğlu, N., Sahin, L., Ganioğlu, E., Ağgez, G., Baştemur, Y., İse, P. (2020). Assessment of natural and anthropogenic radioactivity of the Princes' Islands in the Sea of Marmara. *Water, Air & Soil Pollution*, 231, 1-16. https://doi.org/10.1007/s11270-020-04631-w.

ICRP (International Commission on Radiological Protection). (1991). 1990 Recommendations of the International Commission on Radiological Protection, *Elsevier Health Sciences*, 21, 1-3.

Kayakökü, H., Doğru, M. (2017). Radioactivity analysis of soil samples taken from the western and northern shores of Lake Van, Turkey. *Applied Radiation and Isotopes*, 128, 231–236. https://doi.org/10.1016/j.apradiso.2017.07.019

Kekelidze, N., Teimuraz, J., Tutberidze, B., Tulashvili, E., Mariam, A., Mtsariashvili, L. (2017). Radioactivity of soils in Mtskheta-Mtianeti region (Georgia). *Annals of Agrarian Science*, 15, 304-311. https://doi.org/10.1016/j.aasci.2017.07.003.

Kucukomeroglu B., Yesilbag, Y. O., Kurnaz A., Celik, N., Cevik, U., Celebi, U. (2011). Radiological characterisation of Artvin and Ardahan provinces of Turkey. *Radiation Protection Dosimetry*, 145, 389-394. https://doi.org/10.1093/rpd/ncq442

Kucukomeroglu B., Karadeniz A., Damla N., Yesilkanat C.M., Cevik U. (2016). Radiological maps in beach sands along some coastal regions of Turkey. *Marine Pollution Bulletin*, 112, 255–264. https://doi.org/10.1016/j.marpolbul.2016.08.007

Kurnaz, A., Küçükömeroğlu, B., Keser, R., Okumusoglu, N.T., Korkmaz, F., Karahan, G., Çevik, U. (2007). Determination of radioactivity levels and hazards of soil and sediment samples in Fırtına Valley (Rize, Turkey). *Applied Radiation and Isotopes*, 65, 1281-1289. https://doi.org/10.1016/j.jenvrad.2011.02.009

Kuş, A. (2017). Sakarya İli Toprak Örneklerinde Doğal Radyasyon Düzeyinin Belirlenmesi ve Radon Yayilim Hizlarinin Ölçülmesi, Master Thesis, Sakarya Üniversitesi, Fen Bilimleri Enstitüsü, Sakarya, Türkiye.

Mamont-Ciesla, K., Gwiazdowski, B., Biernacka, M., Zak, A. (1981). Radioactivity of building materials in Poland. *Natural Radiation Environment*, 16(10), 551-557.

Roberto C., Giuseppina I., Gabriella M., Daniela M., Massimo A., Salvatore G., Lenka T. (2015). In situ and laboratory measurements for radon transport process study. *Journal of Radioanalytical and Nuclear Chemistry*, 306, 673–684. https://doi.org/10.1007/s10967-015-4336-6

Suresh Gandhi, M., Ravisankar, R., Rajalakshmi, A., Sivakumar, S., Chandrasekaran, A., Anand, D.P. (2014). Measurements of natural gamma radiation in beach sediments of north east coast of Tamilnadu, India by gamma ray spectrometry with multivariate statistical approach. Journal *of Radiation Research* and Applied Sciences, 7, 7–17. https://doi.org/110.1016/j.jrras.2013.11.001

Şirin M. (2019). Evaluation of radioactive pollution in sediment samples of Borçka Dam Lake, Turkey. *Cumhuriyet Science Journal*, 40(3), 624-639. https://doi.org/10.17776/csj.526652

Taskin H., Karavus M., Ay P., Topuzoglu A., Hidiroglu S., Karahan G. (2009). Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity*, 100, 49–53. https://doi.org/10.1016/j.jenvrad.2008.10.012

Tzortzis M., Tsertos H., Christofides S., Christodoulides G. (2003). Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks. *Radiation Measurements*, 37, 221-229. https://doi.org/10.1016/S1350-4487(03)00028-3

UNSCEAR (United Nations Scientific Committee on the Effect of Atomic Radiation), (2000). Radiation sources and Effects of ionizing radiation, Report to General Assembly with Scientific Annexes, United Nations, New York, USA.