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Determination of the environmental natural radioactivity and mapping of natural background radioactivity of the Gumushane province, Turkey

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Abstract
The aim of the study is to determine the ambient radiation level in Gumushane province. With this aim, the gamma dose ratios absorbed in the air were surveyed by a portable gamma detector. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in soil samples have been measured by the gamma spectrometric analysis system. The gross alpha and beta activity concentrations in drinking water were also determined by the alpha and beta counting system. By considering the geological structure, the soil samples have been obtained from 62 different spots. In addition, 77 samples of natural and tap water have been collected from different points of the province. The samples were analyzed at the Cekmece Nuclear Research and Training Center in Turkey. Absorbed gamma dose rates in the air were measured in 338 different points in the studied area.

Keywords Gumushane air · Water · Soil · Natural radioactivity

Introduction

Human beings have been continuously and inevitably under the influence of radiation since their existence. Radiation is caused by radioactive nuclei in the structure of the world, cosmic heat in the solar system or artificial radiation produced by human beings. Natural resources are very important in the evaluation of radiation dose. The highest amount of annual dose of a human is taken from natural radioactivity. Annual average dose values from natural radiation are 9.5–10% in foods, 8.7% in drinks, 8.7–9% in gamma rays, 17.5–18% in cosmetics, 14.8–15% in cosmic rays and 48–49.4% in radon [1]. The rate of radionuclide concentration in soil, water and air is increased by nuclear tests or nuclear reactor accidents (such as Chernobyl).

There are many studies in the literature about the determination of natural radionuclide concentrations in soil [2–8]. The aim of these studies is to determine the level of natural radioactivity in the country or regionally and to determine how many people are taking these natural sources. Under the influence of radioactive materials in the rocks that pass through the waters of the ground or the depths of the ground. They gain some radioactivity. The most important radioactive elements encountered in groundwater are K^{40}, Rb^{87}, Th^{232}, U^{235} and U^{238} [9, 10]. Studies on the determination of the natural radioactivity level in the waters were carried out only in thermal waters. Because the activity concentration of groundwater is higher than surface water. In recent years, natural radionuclide was found in drinking water, in the underground waters. Mostly uranium-series elements are radium and radon. Radioactive radon, which is the product of the disintegration of ^{226}Ra is found in some underground waters at very high concentrations [1]. It is very difficult to detect the elements of the actinium series in groundwater. Although in some waters ^{232}Th and ^{226}Ra from the thorium series are found in detectable amounts, the ^{220}Rn, which has a very short half-life, does not allow to accumulate in water and rocks [1, 11]. In the researches related to drinking water, total Alpha and Beta activities are generally examined

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[12–16]. Total alpha activity is due to uranium and radium isotopes due to low thorium solubility in natural waters [17]. In principle, although the main cause of Alpha activity is ^{226}Ra. It is sometimes reported to contribute ^{232}Th. ^{210}Po or ^{224}Ra [18]. As such, it is stated that beta activity is mainly caused by ^{40}K and ^{228}Ra [13, 14]. Drinking water in terms of human health, the World Health Organization (WHO) and Turkey Standards Institute (TSE) adopted by the upper limits; the total alpha is 0.1 Bq/l, the total is Beta 1 Bq/l and Tritium 100 Bq/l [11, 19]. The other study, researches determined radiological distribution of gross alpha, gross beta, ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs for a total of 40 natural spring water samples obtained from seven cities of the Eastern Black Sea Region was determined by artificial neural network (ANN) method [20]. Gültekin and Dilek in 2005, In their study on mineral water resources in Gümüşhane, they determined that the total alpha activity in the mineral water resources varies between 122 and 780 mBq/l [12].

In addition, the relationship between the radionuclides in the environment and the radiation dose that people receive from these sources should also be determined. However, after much research, it can be decided whether a region is suitable for natural radiation in terms of healthy legislation [21]. In this field, research studies are carried out in Turkey and abroad [1, 22–26]. For this purpose, research on the International Commission on Radiological Protection (ICRP), United States Radiation Protection and Measurement National Committee (UNSCEAR) and Turkey Atomic Energy Agency Çekmece Nuclear Research and Training Center (TAEK ÇNAEM) is carried out by national and international organizations. The main purpose of the environmental radiation measurements is to determine the radiation type and dose that people receive from the environmental sources and to evaluate the risk. Utilizing natural radioactivity, it is used in various fields such as the explanation of the nuclear structure of the atom, estimation of the age of the world and measurement of the sediment formation rates at the bottom of the oceans. These studies are important in terms of determining both the levels of natural radioactivity and the rate at which people are exposed to radiation from nuclear power plants in the regions where nuclear power plants are established. This study was carried out to determine the environmental radiation of Gumushane.

Materials and methods

Studied area

More than 40% of the pre-Liassic basement rocks of the Eastern Pontides are composed of granitoids. Gümüşhane Batolite is the largest of these granitoids with a surface area of ~ 400 km^2.

Granite, granodiorite and felsic rocks (microgranite, spherulitic dacite and rhyolite) are the main rock types that form the granitoid. Granite and granodiorite are outcropped in the central and northern parts of the batholith and contain mainly hornblende, biotite, plagioclase, K-feldspar and magnetite, apatite and zircon as the secondary component. In contrast, the felsic rocks outcrop in the south and southeast parts of the batholith and consist only of quartz and feldspar. The boundary between granite/granodiorite and felsic rocks is gradual [27].

Gümüşhane province, which has an area of 6575 km^2, is located between 38°45′–40°12′ east longitudes and 39°45′–40°50′ north latitudes in the Black Sea Region. Coordinates of the sample locations were recorded with Garmin Etrex 32x type handset. The coordinates of the obtained samples are introduced to the QGIS program as points and the radioactivity values corresponding to the point coordinates were introduced to the program as attribute data. In order to create radioactivity anomaly maps, anomaly and contour maps were created using the inverse distance weighted (IDW) method from the QGIS program interpolation module. The average height of the city from sea level is 1210 m. Gümüşhane study area where samples are taken were presented in Fig. 1. All samples were collected during June 2016–October 2016.

Determination of radioactivity in water samples

Various drinking water 77 samples were collected from the vicinity of the Gümüşhane province. Of which, 27 from Gümüşhane central district, 9 from Kurtun district, 12 from Siran district, 8 from Kelkit district, 10 from Torul district and 11 from Köse district. In order to determine gross alpha and gross beta activity, a Berthold brand and LB 770 model alpha and beta counter with 10 channels low level present in ÇNAEM laboratory were used. The operation voltage of the detector is 1650 V and its diameter is 5 cm. The used in these kinds of counters contain 90% argon and 10% methane.

The main steps of the measurement procedure are detailed in Ref [29]. 500 mL of the sample to be analyzed was taken and 5 drops of diluted detergent (1 + 4) were added. The beaker placed on hot-late magnetic stirrer was mixed by adding 20 mL of 2 N H_2SO_4. Stir process was continued for 10 min after boiling to ensure more mixing of the solution. Then 1 mL of barium carrier was added to the solution and the stirring process was continued for 30 min. 1 mL of Bromocresol purple indicator, 1 mL of iron carrier and 5 mL of paper pulp/water mixture is added.

Then drops of ammonium hydroxide, 6 N (NH_4OH, 6 N) were added until the color of the solution turns yellow to purple and the stirring process was continued for 30 min more. Then the solution was allowed to stand for precipitation. The precipitate was then filtered through a filter paper

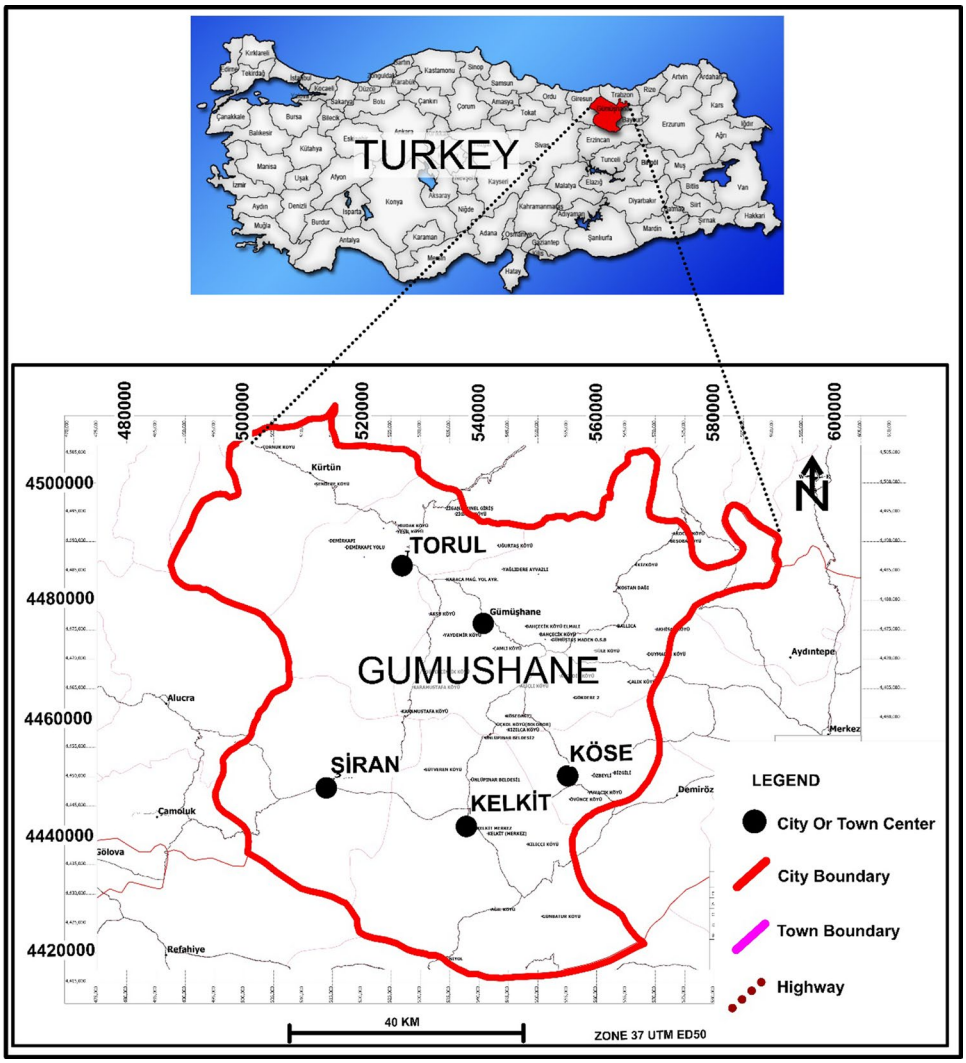

Fig. 1 Study area map in Gumushane province

by the vacuum pump. Finally, the precipitate on the filter paper was allowed to stand for at least 3 h to remove the radon products and dried in a 105 °C oven or under a lamp. The same procedures were performed for blank. (Background activity). The above-mentioned procedures were repeated for each water sample [28–34].

$$\text{Gross alpha activity, pCi/L} = \frac{C_a - C_b}{EV} \quad (1)$$

where E: counter efficiency, cpm/PCi, V: volume analyzed, L, C_a: sample counts per minute, cpm and C_b: reagent blank, cpm.

Determination of radioactivity in soil samples

Various 62 soil samples were collected from the vicinity of the Gümüşhane province. The distribution of the soil samples are such that 23 from the central district of Gümüşhane, 8 from the Kürtün district, 4 from the Şiran district, 9 from the Kelkit district, 8 from the Köse district and 10 from the Torul district. The samples were grounded, homogenized and sieved to about 100 mesh by a crushing machine. Then the samples were dried in an oven at a temperature of 100 °C. Samples were put into plastic cylindrical polyethylene containers. Then they were weighed, sealed and stored at least for 30 days to allow secular equilibrium between radium and thorium and their decay products. Then each sample was measured and the values are given in Bq/kg dry weight. The specific activity concentration of natural radionuclides (of ^{226}Ra, ^{232}Th and ^{40}K) and artificial radionuclide (^{137}Cs) were determined by using Gama-ray spectroscopy at Çekmece Nuclear Research and Training Center (ÇNAEM) [34].

Gamma spectrometry measurements were conducted with a coaxial high purity Ge detector of 15% relative efficiency and resolution 1.2 keV at the 1332 keV gamma of ^{60}Co. The energy calibration and absolute efficiency calibration of

Table 1 Total alpha and total beta values obtained from water sources in Gumushane province

Water samples	Coordinates		Total alpha radioactivity concentration (mBq/l)	Total beta radioactivity concentration (mBq/l)
	Latitude (North)	Longitude (East)		
Bahçecik	40.4328	39.59191	20 ± 1.1	70 ± 4.1
Bahcecik Elmalı	40.44625	39.56161	8 ± 0.9	17 ± 1.2
Bahçecik-Karmut	40.44897	39.60107	38 ± 3.4	27 ± 1.3
Tekke	40.41851	39.61812	8 ± 0.9	50 ± 3.8
Mescitli	40.51482	39.4206	17 ± 2.8	20 ± 1.1
Gümüşhane Center.	40.45936	39.48513	20 ± 1.1	80 ± 4.5
Duymadık	40.39844	39.83029	8 ± 0.9	8 ± 1.1
Güvercinlik	40.37144	39.33838	8 ± 0.9	20 ± 1.1
Gökdere	40.32709	39.66707	8 ± 1.1	20 ± 1.1
Aktutan	40.49188	39.52241	8 ± 0.9	70 ± 4.6
Karamustafa	40.3056	39.28577	8 ± 0.9	17 ± 1.3
Akocak	40.59821	39.88861	8 ± 0.9	40 ± 3.2
Kayabaşı	40.5631	39.82435	8 ± 0.9	30 ± 2.9
Gümüşhane Center	40.46191	39.4703	28 ± 2.9	150 ± 6.6
Geçit	40.3868	39.77254	8 ± 0.9	17 ± 1.3
Arzular	40.41912	39.66275	8 ± 1.1	70 ± 4.2
Çalık	40.35244	39.78751	8 ± 0.9	30 ± 3.1
Ballıca	40.44561	39.76358	8 ± 1.1	17 ± 1.2
Dörtkonak	40.41738	39.37787	30 ± 2.77	90 ± 4.8
Süle	40.40463	39.71357	20 ± 1.1	60 ± 4.1
Yayladere	40.47123	39.78808	8 ± 0.9	30 ± 2.4
Kale	40.38749	39.68998	20 ± 1.1	190 ± 7.9
Yağmurdere	40.57842	39.87116	8 ± 0.9	50 ± 3.7
Akgedik	40.36345	39.6371	17 ± 1.1	30 ± 2.3
Kızılca	40.27436	39.5196	8 ± 0.9	110 ± 4.8
Kırıklı	40.35135	39.55718	20 ± 1.1	70 ± 4.2
Üçkol	40.28339	39.49529	8 ± 0.9	17 ± 1.1
Zigana	40.63324	39.40718	17 ± 1.1	20 ± 1.1
Konacık	40.68226	39.14812	8 ± 0.9	40 ± 3.4
Şendere	40.6841	39.09611	40 ± 3.4	30 ± 2.3
Özkürtün	40.67202	39.13952	3 ± 0.7	8 ± 0.9
Karaçukur	40.64781	39.17919	8 ± 0.9	120 ± 5.2
Zigana	40.61249	39.33365	8 ± 0.9	30 ± 2.4
Tornük	40.74559	38.97914	8 ± 0.9	8 ± 0.9
Çayırçukur	40.67888	39.11127	4 ± 0.8	8 ± 0.9
Kürtün	40.70386	39.08232	4 ± 0.8	8 ± 0.9
Şiran	40.19565	39.13415	4 ± 0.8	4 ± 0.8
Yeşilbük	40.21734	38.98676	8 ± 0.9	8 ± 0.9
Sinanlı	40.13218	39.96355	30 ± 2.2	60 ± 4.1
Seydibaba	40.10705	39.04745	8 ± 0.9	8 ± 0.9
Kılıçtaşı	40.13694	39.3143	8 ± 0.9	40 ± 3.1
Evrenköy	40.24299	39.17581	8 ± 0.9	130 ± 5.2
Sütveren	40.20865	39.33696	8 ± 0.9	40 ± 3.2
Başpınar	40.11576	39.29795	20 ± 1.1	160 ± 5.6
Söğütlü	40.08886	39.2522	8 ± 0.9	17 ± 1.1
Karaşeyh	40.17194	39.1744	28 ± 1.1	58 ± 4.1
Tomara waterfall	40.08149	39.04272	8 ± 0.9	17 ± 1.1
Inkilap	40.42448	39.29282	8 ± 0.9	21 ± 1.1
Yeniyol	39.89353	39.37586	8 ± 0.9	28 ± 1.1

Table 1 (continued)

Water samples	Coordinates		Total alpha radioactivity concentration (mBq/l)	Total beta radioactivity concentration (mBq/l)
	Latitude (North)	Longitude (East)		
Belenli	39.94975	39.54885	28 ± 1.2	58 ± 3.9
Sadak	40.02311	39.61092	17 ± 1.1	80 ± 4.3
Deredolu	40.034	39.303094	8 ± 0.9	40 ± 3.2
Kelkit 1	40.11067	39.4506	8 ± 0.9	70 ± 4.1
Kelkit 2	40.10166	39.47461	17 ± 1.1	80 ± 4.2
Ünlüpınar	40.19157	39.43828	8 ± 0.9	40 ± 3.1
Ünlüpınar	40.26108	39.4696	8 ± 0.9	8 ± 0.9
Köse mountain	40.2971	39.51593	38 ± 3.1	80 ± 4.2
Köse	40.21572	39.64767	8 ± 0.9	150 ± 6.5
Gökçe	40.22069	39.72529	8 ± 0.9	17 ± 1.1
Salyazı	40.25098	39.81705	8 ± 0.9	17 ± 1.1
Bizgili	40.20142	39.75271	8 ± 0.9	8 ± 0.9
Özbeyli	40.197	39.70596	8 ± 0.9	8 ± 0.9
Yuvacık	40.16903	39.697	8 ± 0.9	8 ± 0.9
Övünce	40.15778	39.65628	8 ± 0.9	40 ± 3.1
Akbaba	40.15642	39.60774	8 ± 0.9	30 ± 2.2
Kayadibi	40.20739	39.61183	28 ± 1.2	70 ± 4.1
Kabaktepe	40.22748	39.67411	8 ± 0.9	20 ± 1.1
Torul	40.56113	39.2979	8 ± 0.9	110 ± 4.7
Yağlıdere	40.54131	39.51116	8 ± 0.9	17 ± 1.1
Tokçam	40.61021	39.24815	8 ± 0.9	40 ± 3.1
Cebeci	40.54653	39.41271	30 ± 2.2	50 ± 3.6
Uğurtaş	40.58033	39.50075	8 ± 0.9	20 ± 1.1
Yeşil village	40.60426	39.27697	8 ± 0.9	28 ± 1.1
Demirkapı	40.58342	39.23859	20 ± 1.1	20 ± 1.1
Demirkapı	40.58956	39.12725	17 ± 1.1	80 ± 4.1
Demirkapı	40.55102	39.12297	110 ± 4.6	130 ± 5.2
Altınpınar	40.56265	39.20517	8 ± 0.9	20 ± 1.1

the spectrometer were carried out using calibration sources. The gamma ray transitions of energies 351.9 keV (^{214}Pb) and 609.3 keV (^{214}Bi) were used to determine the activity concentration of the ^{226}Ra series [31]. The gamma-ray lines at 911.1 keV (^{228}Ac) and 583.1 keV (^{208}Tl) were used to determine the activity concentration of the ^{232}Th series [31]. The activity concentrations of ^{40}K were measured directly through the gamma line emission at 1460 keV. The 661.6 keV gamma transitions was used to determine the ^{137}Cs concentrations. The activity concentrations for the natural radionuclides in the measured samples were computed using the following relation; [31].

$$C_s = \frac{N_a}{\varepsilon P t w} (\mathrm{B\,q \cdot kg^{-1}}) \tag{2}$$

where N_a is the net counting rate of gamma ray, ε is the counting efficiency of the used detector, P the absolute transition of gamma decay, t the counting time in seconds and w the weight of dried sample in kg.

The radium equivalent activity is calculated from the following equation: [31, 35].

$$Ra_{\mathrm{eq}} = C_{\mathrm{Ra}} + 1.43 C_{\mathrm{Th}} + 0.077 C_{\mathrm{K}} \tag{3}$$

The gamma absorbed dose rates in air were calculated using the following formula [31, 35]:

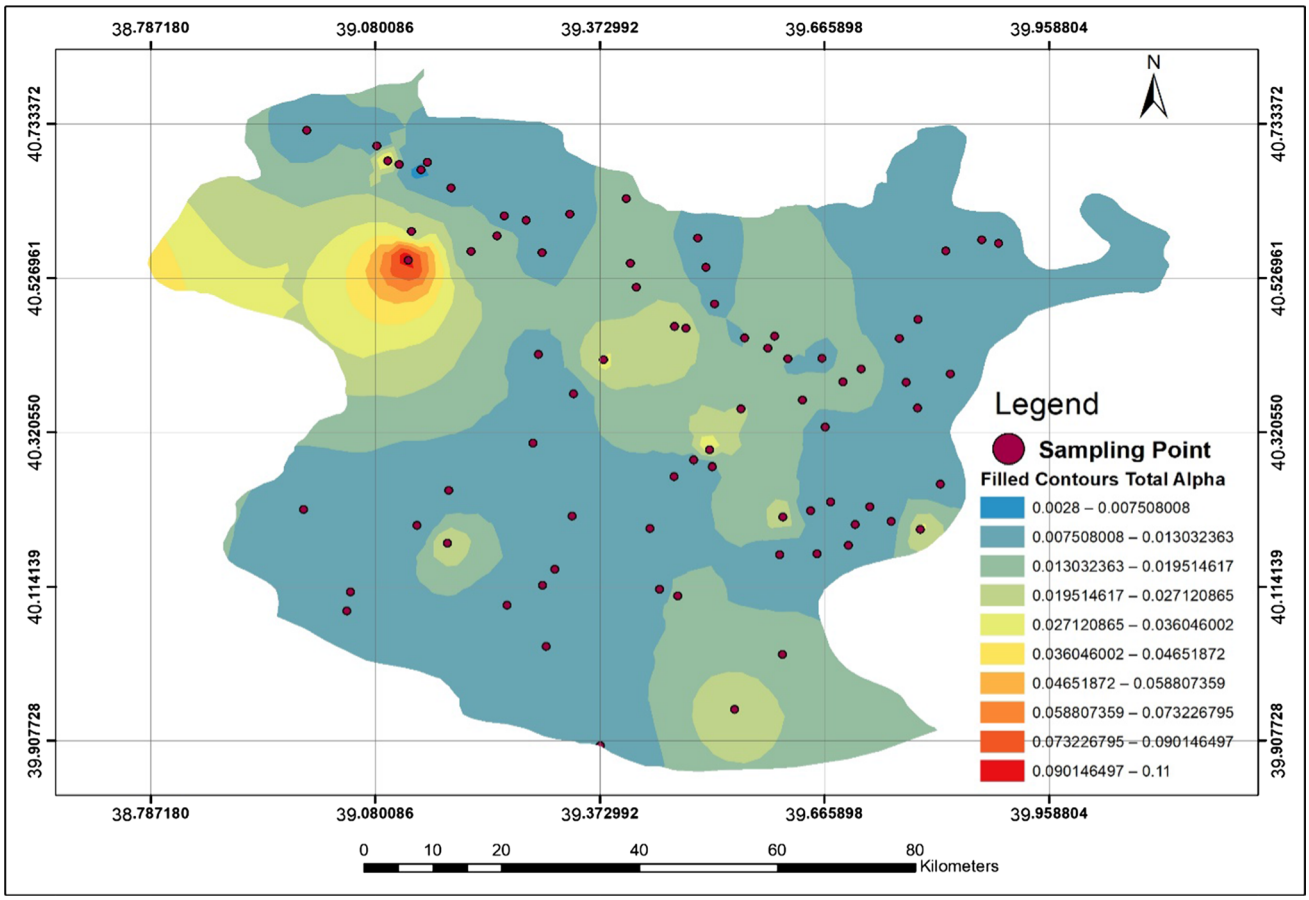

Fig. 2 Total alpha radioactivity distribution map in Gumushane province waters (mBq/l)

$$D\left(\mathrm{nGy\,h^{-1}}\right) = 0.462C_{\mathrm{Ra}} + 0.604C_{\mathrm{Th}} + 0.0417C_{\mathrm{K}} \tag{4}$$

The external hazard index (H_{ex}) due to the emitted gamma rays for each sample was calculated according to the following formula [31, 35]:

$$H_{\mathrm{ex}} = \frac{C_{\mathrm{Ra}}}{370} + \frac{C_{\mathrm{Th}}}{259} + \frac{C_{\mathrm{K}}}{4810} \leq 1 \tag{5}$$

The annual effective dose rate (AEDR) was calculated using the following equation [31, 35]:

$$\mathrm{AEDR}\left(\mathrm{\mu Sv\,y^{-1}}\right) = D\left(\mathrm{nGy\,h^{-1}}\right) \times 8760\left(\mathrm{h\,y^{-1}}\right) \times 0.2 \times 0.7\,\mathrm{SvG\,y^{-1}} \times 10^{-3}. \tag{6}$$

Carrying out air measurements

In this study, 338 measurements were taken from Gümüşhane Province and its districts in order to determine environmental gamma dose rates. In this study, the portable aluminum scintillation detector, which brands the LUDLUM brand 2241-2 Survey Meter, was used to determine the external gamma radiation level. With the environmental radiation monitor, measurements were taken from the height of 1 m above the ground during the gamma radiation

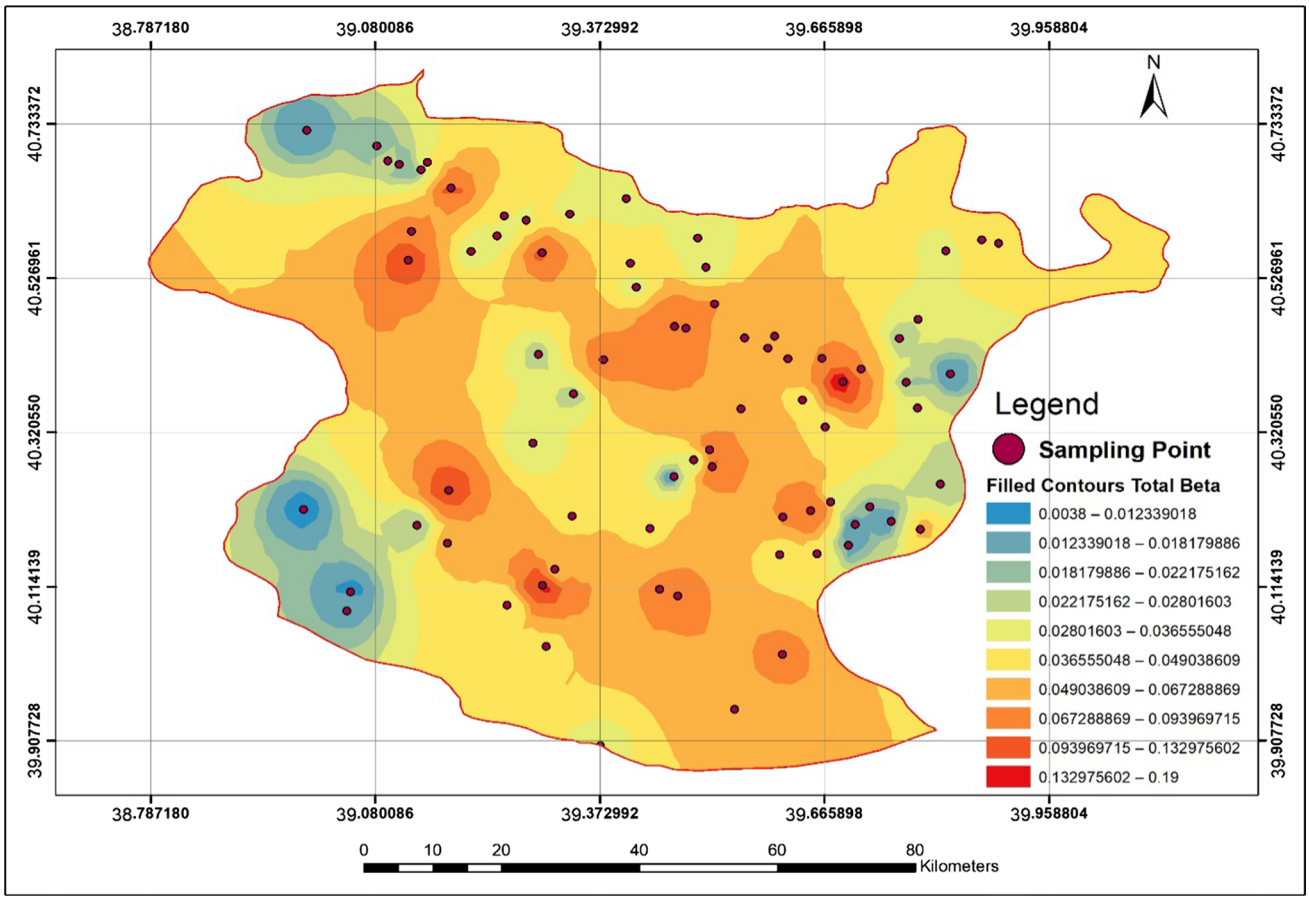

Fig. 3 Total beta radioactivity distribution map in Gumushane province waters (mBq/l)

measurements, after waiting 2–3 min for the device to reach a certain equilibrium. Radiation levels were read from the digital display and recorded in μSv/h.

Results

In this study, radioactivity levels were determined in water, soil samples and air. Kelkit, Şiran, Torul, Kürtün and Köse districts and villages are the districts of the studied area. Water samples were counted in the alpha–beta counting system and soil samples were counted in the gamma spectrometer system. The air measurement was carried out with the 2241-2 Survey Meter scintillation gamma detector.

Water samples

The results are presented in Table 1. It can be seen from the table that the minimum and the maximum gross alpha and gross beta activity results 3 mBq/L, 110 mBq/L, 4 mBq/L and 190 mBq/L, respectively. The mean value for gross alpha is 13.97 mBq/L, whereas the mean values for gross beta is 46.77 mBq/L. Gross alpha and gross beta activity

Table 2 Activity concentrations in soil samples in Gumushane province (Bq/kg)

Soil samples	Latitude (North)	Longitude (East)	Cs-137 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)	Ra eq (Bq/kg)	D(n Gy h^{-1})	Hex	AEDR (μSv y^{-1})
Karaca Cave	40.52508	39.38580	6.9 ± 0.7	23.3 ± 1.7	21.1 ± 1.3	309.8 ± 31.8	75.1	36.4	0.2	44.6
Yağlıdere Ayvazlı	40.54131	39.51116	2.1 ± 0.2	18.8 ± 1.2	27.6 ± 1.9	547.1 ± 38.4	96.6	48.2	0.3	59.1
Uğurtaş	40.58033	39.50075	5.7 ± 0.6	51.3 ± 3.6	68.5 ± 3.8	976.7 ± 71.1	217.7	105.9	0.6	129.8
Olucak	40.53294	39.59115	0.8 ± 0.1	7.1 ± 0.7	23.2 ± 1.4	393.2 ± 34.5	67.9	33.7	0.2	41.4
Yeşil	40.60426	39.27697	0.8 ± 0.1	10.3 ± 0.8	18.4 ± 1.2	518.2 ± 37.5	73.1	37.6	0.2	46.1
Aksüt	40.61021	39.24815	1.2 ± 0.1	37.1 ± 2.2	101.5 ± 4.5	856.4 ± 65.4	242.2	114.1	0.7	140.0
Torul	40.57876	39.30072	2.9 ± 0.3	21.6 ± 1.3	36.7 ± 2.2	537.1 ± 38.1	111.8	54.6	0.3	66.9
Demirkapı-1	40.57876	39.16344	0.8 ± 0.1	67.8 ± 3.8	79.9 ± 4.1	1032.3 ± 72.1	254.4	122.7	0.7	150.5
Demirkapı-2	40.58956	39.12725	18.6 ± 1.2	48.1 ± 2.9	68.8 ± 4.1	788.1 ± 56.4	201.7	96.7	0.6	118.6
Altınpınar	40.56265	39.20517	2.2 ± 0.2	14.6 ± 1.2	25.2 ± 1.5	442.6 ± 36.1	81.7	40.4	0.2	49.6
Köse mountain	40.29710	39.51593	0.9 ± 0.1	19.1 ± 1.2	31.1 ± 1.8	679.9 ± 48.8	111.2	56.0	0.3	68.6
Bizgili	40.20142	39.75271	5.7 ± 0.6	12.9 ± 0.9	24.2 ± 1.5	540.7 ± 38.4	85.5	43.2	0.2	52.9
Özbeyli	40.19700	39.70596	5.0 ± 0.5	9.6 ± 0.8	22.1 ± 1.3	462.4 ± 36.8	73.5	37.0	0.2	45.4
Yuvacık	40.16903	39.69700	6.2 ± 0.7	6.9 ± 0.7	17.2 ± 1.1	414.7 ± 35.1	60.6	30.9	0.2	37.9
Övünce	40.15778	39.65628	2.7 ± 0.3	19.9 ± 1.2	21.1 ± 1.2	365.3 ± 32.1	75.7	37.2	0.2	45.6
Akbaba-1	40.15642	39.60774	2.3 ± 0.2	21.1 ± 1.3	50.3 ± 2.9	923.9 ± 68.4	157.8	78.7	0.4	96.5
Akbaba-2	40.16769	39.59963	0.9 ± 0.1	10.1 ± 0.8	19.5 ± 1.2.	925.1 ± 68.7	102.8	55.0	0.3	67.5
Kabuktepe	40.22748	39.67411	3.2 ± 0.3	18.1 ± 1.2	33.7 ± 1.9	637.3 ± 41.6	110.8	55.3	0.3	67.8
Yeniyol	39.89353	39.37586	1.4 ± 0.1	10.3 ± 0.8	15.1 ± 1.1	296.9 ± 27.4	52.7	26.3	0.2	32.2
Günbatur	39.96315	39.59362	4.4 ± 0.5	14.8 ± 1.2	24.7 ± 1.5	418.6 ± 32.5	79.6	39.3	0.2	48.2
Ağıl	39.97521	39.48095	11.8 ± 0.8	5.8 ± 0.6	11.1 ± 0.8	355.4 ± 32.2	46.6	24.2	0.1	29.7
Kılıççı	40.08343	39.56221	2.1 ± 0.2	10.4 ± 0.8	18.7 ± 1.2	266.4 ± 23.3	56.0	27.3	0.2	33.5
Kelkit	40.10166	39.47461	5.9 ± 0.6	10.8 ± 0.8	20.3 ± 1.2	251.4 ± 20.4	57.5	27.8	0.1	34.1
Ünlüpınar-1	40.19157	39.43828	3.7 ± 0.4	15.1 ± 1.2	15.1 ± 1.2	341.1 ± 27.7	60.5	30.3	0.1	37.2
Ünlüpınar-2	40.26108	39.46960	0.8 ± 0.1	7.8 ± 0.7	12.4 ± 0.9	202.9 ± 16.2	39.9	19.6	0.1	24.1
Alıçlı	40.34708	39.54758	0.1 ± 0.0	40.2 ± 2.3	32.2 ± 1.8	752.3 ± 52.4	139.1	69.5	0.3	85.2
Kelkit-1	40.11067	39.45060	0.4 ± 0.1	10.2 ± 0.8	17.3 ± 1.1	207.5 ± 16.9	49.6	23.9	0.1	29.2
Kelkit-2	40.90033	39.06505	1.3 ± 0.1	21.2 ± 1.3	46.5 ± 2.4	1103.1 ± 71.2	165.0	83.9	0.4	102.9
Şiran	40.19565	39.13415	0.6 ± 0.1	15.2 ± 1.2	25.6 ± 1.6	498.6 ± 39.7	86.9	43.4	0.2	53.1
Karamustafa	40.30560	39.28577	0.9 ± 0.1	11.5 ± 0.9	21.9 ± 1.3	1137.4 ± 73.4	122.5	66.0	0.3	80.9
Sütveren	40.20865	39.33696	0.7 ± 0.1	9.1 ± 0.8	17.8 ± 1.2	309.9 ± 28.4	56.3	27.9	0.1	34.2
Taşlıca	40.71637	39.04572	1.1 ± 0.1	23.4 ± 1.7	29.8 ± 1.8	179.5 ± 25.1	78.7	36.3	0.2	44.5
Tornük	40.74559	38.97914	4.9 ± 0.5	34.2 ± 2.1	70.5 ± 4.1	295.6 ± 27.1	155.7	70.7	0.4	86.7
Budak	40.61441	39.28197	1.6 ± 0.1	120.3 ± 9.9	159.5 ± 13.1	1222.8 ± 120.1	434.0	202.9	1.2	248.8
Zigana-1	40.63324	39.40718	1.2 ± 0.1	9.1 ± 0.8	9.3 ± 0.8	385.1 ± 35.4	49.4	25.9	0.1	31.7
Zigana-2	40.61249	39.33365	7.6 ± 0.9	24.5 ± 1.7	21.1 ± 1.3	699.7 ± 48.8	103.7	53.3	0.2	65.3
Şendere-2	40.68410	39.09611	2.3 ± 0.2	12.3 ± 0.9	18.7 ± 1.2	895.1 ± 62.5	101.8	54.3	0.3	66.6

Table 2 (continued)

Soil samples	Latitude (North)	Longitude (East)	Cs-137 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)	Ra eq (Bq/kg)	D(n Gy h^{-1})	Hex	AEDR (μSv y^{-1})
Limni lake	40.63937	39.41301	7.2 ± 0.9	40.3 ± 2.3	71.1 ± 4.1	732.1 ± 51.4	193.3	92.1	0.5	112.9
Zigana-3	40.64310	39.38582	1.3 ± 0.1	39.6 ± 2.2	61.1 ± 3.1	800.9 ± 55.8	183.0	88.6	0.5	108.6
Ballıca	40.44561	39.76358	1.1 ± 0.1	10.8 ± 0.8	14.7 ± 1.2	274.4 ± 24.1	51.2	25.4	0.1	31.1
Çamlı	40.40971	39.48990	1.9 ± 0.2	40.2 ± 2.3	106.3 ± 7.9	968.8 ± 69.8	260.1	123.2	0.7	151.1
Bahçecik	40.43280	39.59191	9.8 ± 0.8	15.5 ± 1.2	17.5 ± 1.2	382.6 ± 34.7	67.5	33.8	0.2	41.3
Akocak	40.59821	39.88861	21.4 ± 1.2	14.1 ± 1.2	24.1 ± 1.4	352.9 ± 31.9	73.3	35.8	0.2	43.8
Gümüştaş	40.42357	39.61811	0.6 ± 0.1	1.2 ± 0.2	1.8 ± 0.3	50.8 ± 2.9	7.4	3.8	0.1	4.6
Duymadık	40.39844	39.83029	1.1 ± 0.1	5.1 ± 0.6	7.6 ± 0.7	243.2 ± 14.3	33.1	17.1	0.1	20.9
Yaydemir	40.43230	39.38044	5.6 ± 0.6	115.4 ± 8.7	133.1 ± 9.4	1001.2 ± 70.5	375.9	175.5	1.1	215.2
Çalık	40.35244	39.78751	1.3 ± 0.1	21.8 ± 1.3	39.2 ± 2.3	754.6 ± 53.6	130.8	65.2	0.3	80.1
Süle	40.40463	39.71357	3.8 ± 0.4	23.8 ± 1.7	40.4 ± 2.3	644.4 ± 44.1	126.8	62.3	0.3	76.4
İkiz	40.54735	39.80526	9.5 ± 0.8	29.6 ± 2.1	41.5 ± 2.3	1050.2 ± 74.1	162.6	82.6	0.4	101.2
Akgedik	40.36345	39.63710	6.3 ± 0.7	9.7 ± 0.8	17.5 ± 1.2	907.9 ± 64.9	98.4	52.9	0.3	64.9
Boyluca	40.42571	39.35130	0.7 ± 0.1	85.8 ± 5.1	95.7 ± 7.1	1043.4 ± 73.8	295.8	140.9	0.8	172.9
Aksu	40.46789	39.34835	2.2 ± 0.2	36.4 ± 2.2	71.7 ± 4.1	976.7 ± 69.9	207.4	100.8	0.6	123.7
Gökdere 2	40.32709	39.66707	16.5 ± 1.1	27.8 ± 1.9	54.9 ± 2.7	948.6 ± 66.9	172.8	85.6	0.5	105.1
Karamustafa	40.34599	39.31212	0.3 ± 0.1	26.9 ± 1.9	46.7 ± 2.5	770.8 ± 54.1	147.8	72.8	0.4	89.3
Beşoba	40.58587	39.88265	9.8 ± 0.8	22.6 ± 1.3	33.2 ± 1.9	633.6 ± 43.1	114.5	56.9	0.3	69.8
Akhisar	40.43962	39.84900	0.2 ± 0.0	18.2 ± 1.2	36.5 ± 2.1	767.1 ± 53.3	124.1	62.4	0.3	76.6
Karmut	40.42427	39.60477	0.7 ± 0.1	13.1 ± 1.1	18.1 ± 1.2	384.2 ± 27.8	66.1	33.1	0.2	40.5
Üçkol	40.28339	39.49529	3.7 ± 0.4	31.3 ± 2.1	53.1 ± 2.9	1047.9 ± 74.1	180.5	90.2	0.5	110.6
Kızılca	40.27436	39.51960	1.4 ± 0.1	11.2 ± 0.9	33.6 ± 1.9	864.5 ± 60.6	119.9	61.5	0.3	75.5
Güvercinlik	40.37144	39.33838	1.1 ± 0.1	13.3 ± 1.1	18.4 ± 1.2	534.8 ± 35.6	77.1	39.5	0.2	48.5
Kostan mountain	40.50931	39.76628	0.4 ± 0.1	18.3 ± 1.2	28.3 ± 1.7	752.3 ± 52.7	111.5	56.9	0.3	69.8
Bahçecik-Elmalı	40.44625	39.56161	1.6 ± 0.2	23.1 ± 1.7	36.1 ± 2.1	470.4 ± 35.6	107.6	52.1	0.3	63.8

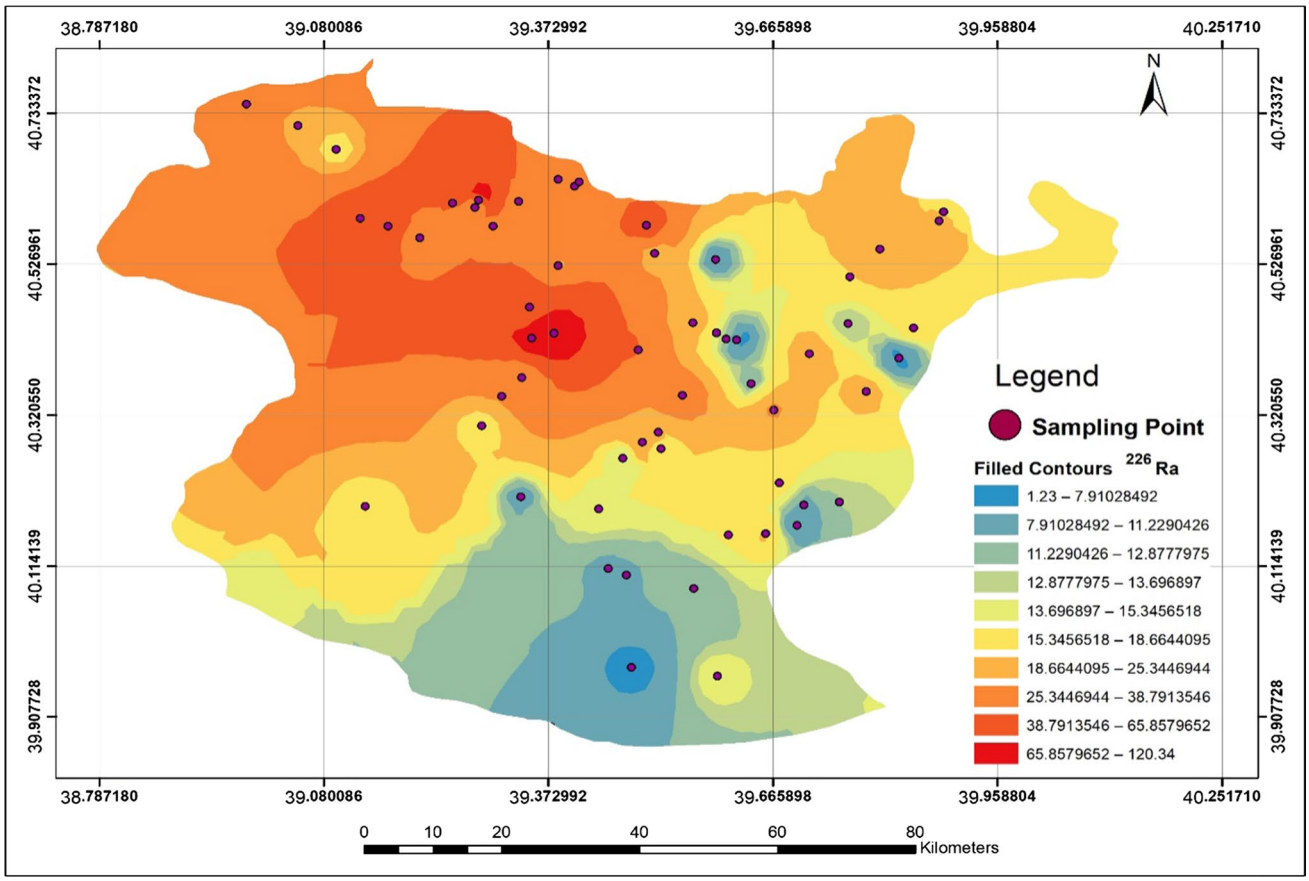

Fig. 4 The ^{226}Ra iso-activity map of the soil of Gumushane province (Bq/kg)

results with the sampling points were presented in Figs. 2 and 3, respectively.

Soil samples

The specific activity concentration of natural radionuclides (of ^{226}Ra, ^{232}Th and ^{40}K) and artificial radionuclide (^{137}Cs) were determined by using Gama-ray spectroscopy present in Çekmece Nuclear Research and Training Center (ÇNAEM). Activity concentrations and mean radium equivalent activity (Ra_{eq}) of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs are presented in Table 2. It was found that activity concentrations ranged from 1.23 to 120.34 Bq/kg for ^{226}Ra, from 1.86 to 159.5 Bq/kg for ^{232}Th and from 50.89 to 1223 Bq/kg for ^{40}K. ^{37}Cs activity concentration was found to range from 0.1 to 21.47 Bq/kg. Obtained values show that the mean radium equivalent activity (Ra_{eq}) were from 7.45 to 434 Bq/kg. The gamma absorbed dose rates in air were in the range of 3.7–202.9 nGy h^{-1}, with an arithmetic mean of 61 nGy h^{-1}, while the annual effective dose rates (AEDR) were determined to be in the range of 4.67–248.8 μSv y^{-1}. External hazard index (Hex) for the soil samples were in the range of 0.02–1.19. The results of activity concentrations are presented in Figs. 4, 5, 6 and 7.

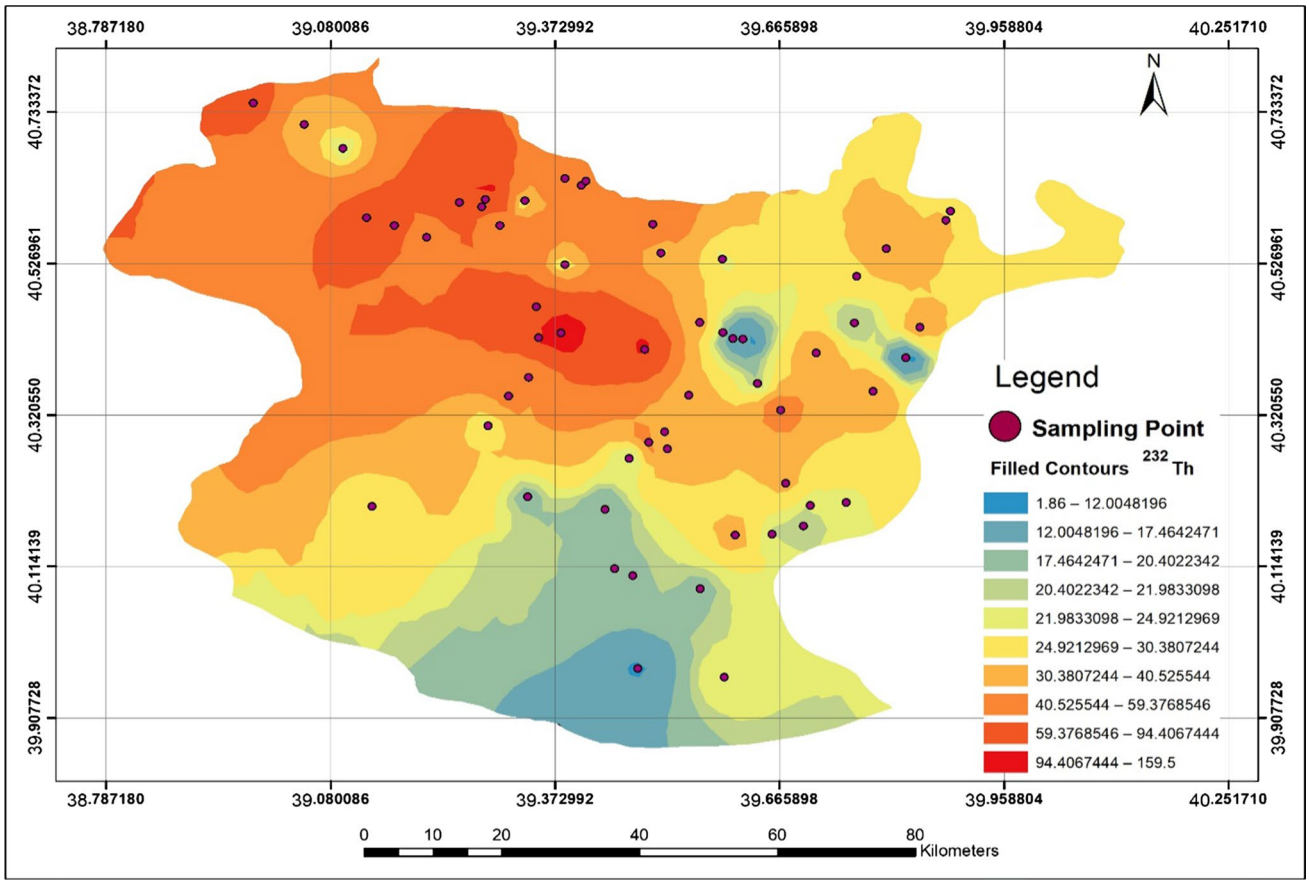

Fig. 5 The ^{232}Th iso-activity map of the soil of Gumushane province (Bq/kg)

Air measurements

The coordinates and measurement values of natural radioactivity measurements made in the air from Gümüşhane, Kelkit, Şiran, Torul, Kürtün and Köse districts are given in Table 3. In addition, the data points of the air data and the map are given in Fig. 8.

The average radiation value in Gümüşhane province is 0.1058 µSv/h. The highest and lowest radiation value in the air environment in the province of Gümüşhane is in the village of Yaydemir 0.405 µSv/h and in the village of Harmancık 0.023 µSv/h, respectively.

Discussion

In this study, the lowest and the highest gross alpha activities in water samples were found in the range of 3–110 mBq/L and gross beta activity was in the range of 4–190 mBq/L. The mean values for gross alpha and gross beta activities were 15.06 mBq/L and 48.05 mBq/L, respectively. In 2016, Kaya and his colleagues conducted a study in tap and natural water samples collected only from the Gumushane city center and Bahcecik village and they found that the gross alpha and gross beta activities were in the range 10–15 mB/L and 12–128 mB/L, respectively [16]. This may be because the region we are investigating is more extensive and we have taken water samples from regions where concentrations

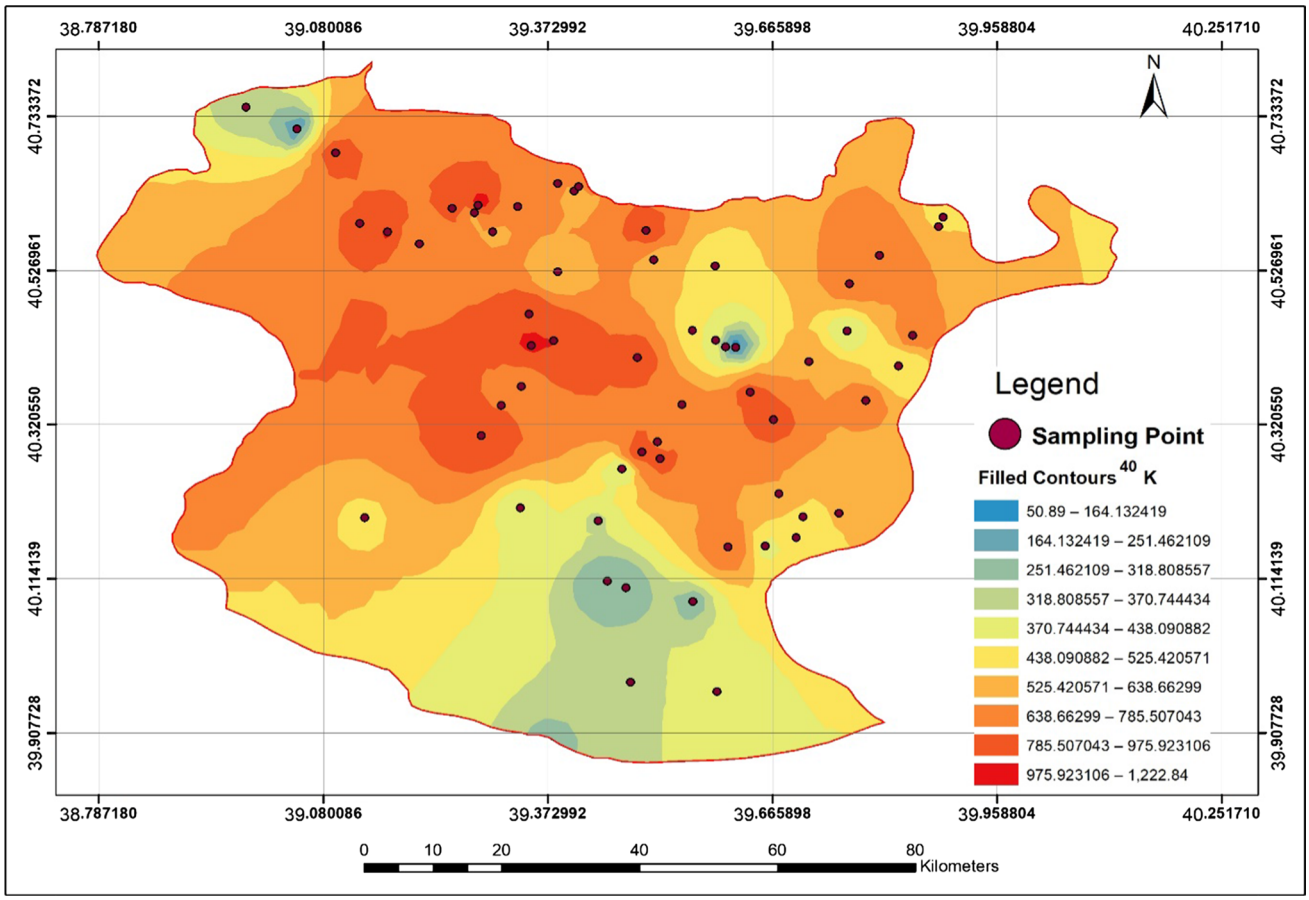

Fig. 6 The ^{40}K iso-activity map of the soil of Gumushane province (Bq/kg)

of ^{226}Ra, ^{232}Th, ^{210}Po or ^{224}Ra are relatively higher, which affect gross alpha and gross beta activity concentrations [18]. In 2005, Gültekin and Dilek determined the gross alpha and gross beta activity concentrations in mineral water samples in the Gümüşhane center ranged from 122 to 780 mBq/L and from 67 to 401 mBq/l, respectively [12]. As can be seen, gross alpha and gross beta activity concentrations in mineral waters are considerably higher than those in natural spring drinking waters. It is also seen that gross alpha and gross beta activity concentrations are relatively high in the water that comes into contact with environments containing elevated concentrations of thorium and uranium elements. It is seen that the results of the current study are below the upper limit values of World Health Organization (WHO), which are 0.1 Bq/L for gross alpha and 1 Bq/L for gross beta.

In the current study, we found that the absorbed gamma dose rate in air was 0.106 µSv/h. The measured highest absorbed gamma dose rate (0.405 µSv/h) was recorded in the air of the Yaylademir village, which is located between 40.4323 N and 39.38044 E. The lowest absorbed gamma dose rate of 0.023 µSv/h was recorded in the air of Harmancık village located in 40.43896 N and 39.63322 E. Considering the mean absorbed gamma dose rate for Turkey (90 nSv/h) it can be seen that the result of the current study is close that value. In 2011 some searchers determined the absorbed gamma dose rate for the Gumushane province to be as average 0.150 µSv/h [36]. As seen, this value is relatively

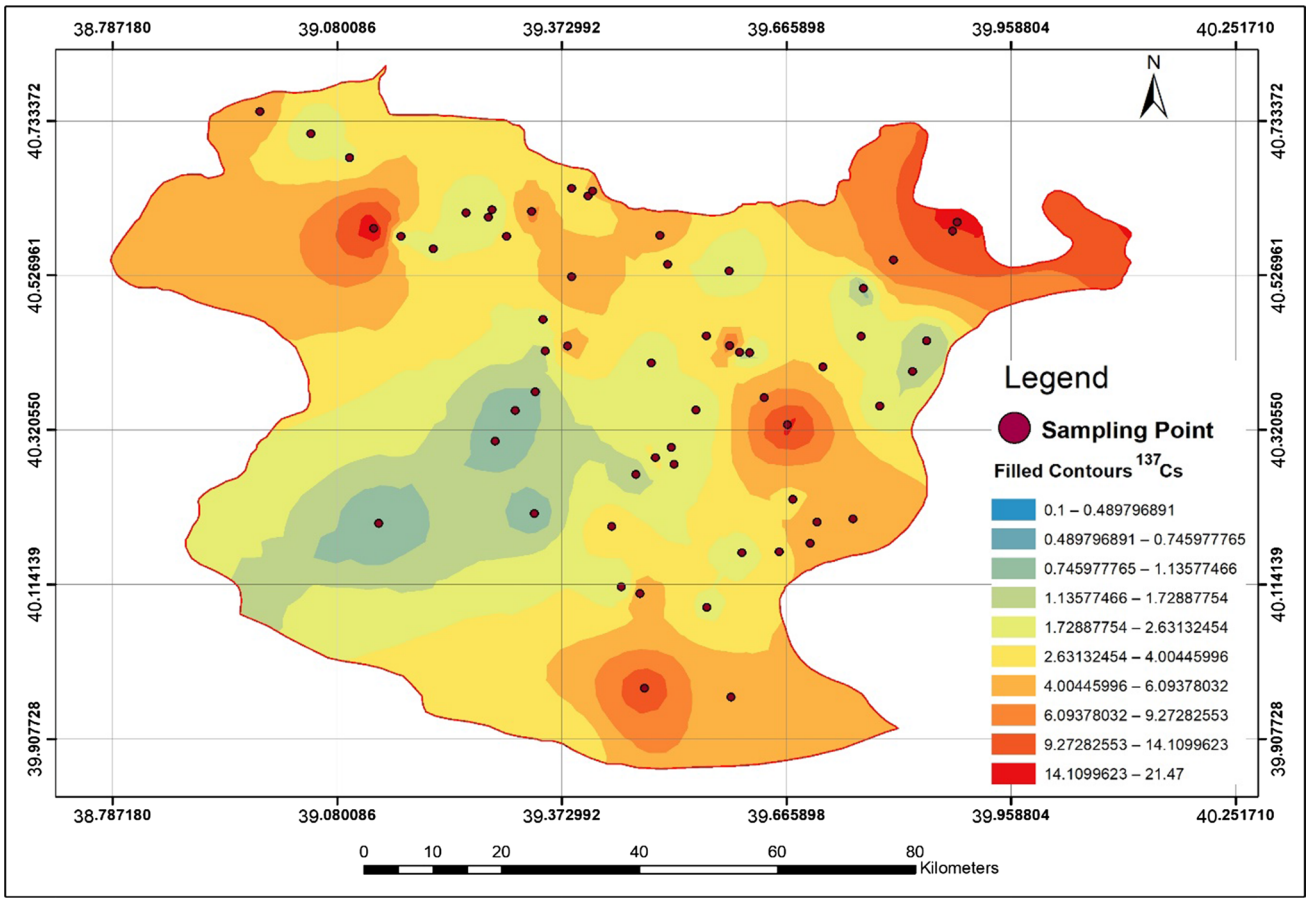

Fig. 7 The ^{137}Cs iso-activity map of the soil of Gumushane province (Bq/kg)

higher than our finding. This might be explained by the fact that Maden and his colleagues carried out their study in a limited region and fewer sampling points were considered [36].

In this study, activity concentrations in surface soil samples were found to range from 1.8 ± 0.3 Bq/kg–159.5 ± 13.1 Bq/kg for ^{232}Th, 1.2 ± 0.2 Bq/kg–120.3 ± 9.9 Bq/kg for ^{226}Ra, 50.8 ± 2.9 Bq/kg–1223 ± 120 Bq/kg for ^{40}K and 0.3 Bq/kg–21 ± 2 Bq/kg for ^{137}Cs. The mean values for the radionuclide concentrations were found to be 38.4 Bq/kg for ^{232}Th, 24.5 Bq/kg for ^{226}Ra, 621.4 Bq/kg for ^{40}K and 3.7 Bq/kg for ^{137}Cs, respectively.

In the UNSCEAR (2000) report, the weighted world average values for ^{232}Th, ^{226}Ra and ^{40}K activity concentrations in the Earth's crust are given as 45, 32 and 420 Bq/kg, respectively [37–39]. In this study, it is seen that the average value of ^{40}K activity is above the world average. Radioactivity concentration of natural radionuclides are strongly correlated with the geology of the region. It has been studied that the Gümüşhane province contains eocene volcanic rocks. Volcanic rocks are basaltic andesite, basaltic trachy andesite, trachy andesite, andesite, dacite and rhyolite in composition, and consists of mainly plagioclase, alkali feldspar, quartz, hornblende, augite and biotite minerals. These rock type shows calc-alkaline affinities and have high K contents [40]. The reason that the ^{40}K activity concentration is higher than the world average could be related to the potassium concentration in the rocks that the province is build upon.

Table 3 Coordinates and measurement values of points in air measurements in Gümüşhane province

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
1	40.26198	39.4696	0.03
2	40.22783	39.43828	0.032
3	40.22783	39.43828	0.07
4	40.14494	39.43284	0.085
5	40.11067	39.4506	0.109
6	40.07336	39.49655	0.074
7	40.03636	39.50754	0.139
8	39.99304	39.54741	0.089
9	39.97521	39.98095	0.061
10	39.95787	39.41604	0.075
11	39.92088	39.40959	0.138
12	39.89353	39.37586	0.0996
13	39.94067	39.5132	0.107
14	39.94975	39.54885	0.084
15	39.95354	39.58304	0.125
16	39.96315	39.59362	0.084
17	39.96311	39.61306	0.093
18	40.02311	39.61092	0.074
19	40.02311	39.6155	0.058
20	40.07955	39.6035	0.06
21	40.08543	39.56221	0.071
22	40.10168	39.5138	0.066
23	40.10166	39.47461	0.083
24	40.35135	39.55187	0.087
25	40.34708	39.54758	0.153
26	40.44039	39.51586	0.16
27	40.44027	39.51589	0.093
28	40.2971	39.51589	0.168
29	40.29409	39.57372	0.171
30	40.27722	39.60003	0.134
31	40.2436	39.62799	0.097
32	40.21572	39.64767	0.115
33	40.22748	39.67411	0.114
34	40.22069	39.72529	0.108
35	40.22596	39.78343	0.145
36	40.25098	39.81705	0.107
37	40.20142	39.75271	0.116

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
38	40.197	39.70596	0.084
39	40.16903	39.697	0.083
40	40.15778	39.65628	0.076
41	40.181	39.66255	0.092
42	40.15642	39.60774	0.086
43	40.16769	39.59963	0.143
44	40.20739	39.61183	0.129
45	40.51482	39.42061	0.105
46	40.49092	39.46062	0.095
47	40.52508	39.3859	0.068
48	40.54653	39.41271	0.056
49	40.555	39.4408	0.079
50	40.55315	39.4837	0.097
51	40.54131	39.51116	0.091
52	40.54696	39.56317	0.14
53	40.533	39.59115	0.133
54	40.55168	39.57041	0.138
55	40.58033	39.50075	0.178
56	40.55363	39.4105	0.082
57	40.52905	39.34337	0.072
58	40.59445	39.31537	0.208
59	40.56113	39.2979	0.108
60	40.56905	39.30075	0.117
61	40.59266	39.306	0.068
62	40.60368	39.28381	0.123
63	40.60368	39.27697	0.086
64	40.61384	39.26269	0.065
65	40.61021	39.24815	0.21
66	40.58342	39.23859	0.104
67	40.57058	39.25351	0.171
68	40.56778	39.2206	0.122
69	40.57074	39.19945	0.178
70	40.57876	39.16344	0.255
71	40.58956	39.12725	0.167
72	40.551	39.12297	0.126
73	40.54861	39.29452	0.137

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
74	40.51607	39.28093	0.087
75	40.56265	39.20517	0.111
76	40.41757	39.58385	0.087
77	40.41851	39.60271	0.09
78	40.42427	39.60477	0.078
79	40.4238	39.59629	0.068
80	40.43055	39.59807	0.074
81	40.43285	39.59497	0.078
82	40.4377	39.59024	0.072
83	40.43919	39.58051	0.077
84	40.4464	39.57325	0.062
85	40.44625	39.56161	0.118
86	40.4475	39.56157	0.089
87	40.44788	39.56152	0.105
88	40.40563	39.60777	0.086
89	40.39401	39.65505	0.078
90	40.3788	39.645	0.075
91	40.36345	39.6371	0.098
92	40.36111	39.68806	0.098
93	40.32709	39.66707	0.152
94	40.34978	39.68949	0.106
95	40.38487	39.7344	0.078
96	40.38328	39.78672	0.073
97	40.37145	39.83838	0.082
98	40.39844	39.8329	0.056
99	40.38092	39.80114	0.068
100	40.35244	39.78757	0.055
101	40.3868	39.77254	0.085
102	40.38749	39.68998	0.072
103	40.40463	39.71357	0.082
104	40.40525	39.72314	0.118
105	40.40528	39.72317	0.037
106	40.39688	39.70687	0.072
107	40.36757	39.68473	0.074
108	40.40318	39.64328	0.07
109	40.41912	39.66275	0.065

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
110	40.43584	39.69928	0.081
111	40.43985	39.72945	0.128
112	40.44175	39.74057	0.134
113	40.44561	39.76358	0.092
114	40.46198	39.80284	0.088
115	40.44377	39.83	0.124
116	40.43962	39.849	0.138
117	40.47123	39.78808	0.147
118	40.5002	39.76774	0.163
119	40.50831	39.76628	0.144
120	40.53379	39.78952	0.178
121	40.54735	39.80526	0.192
122	40.5631	39.82435	0.147
123	40.54265	39.80327	0.184
124	40.5772	39.86728	0.113
125	40.57842	39.87116	0.108
126	40.58587	39.88265	0.141
127	40.59821	39.88861	0.113
128	40.43969	39.71192	0.106
129	40.49671	39.45254	0.11
130	40.51997	39.40746	0.058
131	40.52419	39.3605	0.076
132	40.54363	39.32446	0.128
133	40.58544	39.31021	0.087
134	40.61249	39.33365	0.162
135	40.6484	39.33548	0.12
136	40.65443	39.36519	0.14
137	40.6431	39.38582	0.207
138	40.65578	39.40292	0.158
139	40.63899	39.40518	0.1
140	40.63229	39.40718	0.09
141	40.6182	39.4125	0.181
142	40.639	39.413	0.201
143	40.61063	39.39602	0.142
144	40.608	39.36476	0.102
145	40.60864	39.34773	0.094

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
146	40.60185	39.33209	0.096
147	40.59678	39.31939	0.078
148	40.58344	39.31805	0.11
149	40.57929	39.30885	0.102
150	40.60153	39.30461	0.059
151	40.60701	39.30196	0.1
152	40.6708	39.30409	0.106
153	40.61441	39.28197	0.357
154	40.62165	39.26705	0.394
155	40.62302	39.24459	0.18
156	40.6384	39.21096	0.118
157	40.64781	39.17919	0.075
158	40.65339	39.1418	0.052
159	40.67202	39.13952	0.081
160	40.67305	39.14057	0.096
161	40.68226	39.14812	0.065
162	40.68783	39.11739	0.078
163	40.70386	39.08232	0.12
164	40.7123	39.05887	0.175
165	40.71638	39.04573	0.155
166	40.73433	39.00816	0.116
167	40.74559	38.97914	0.115
168	40.74624	38.96891	0.124
169	40.68395	39.12139	0.092
170	40.68126	39.11488	0.054
171	40.67888	39.11127	0.052
172	40.67429	39.10625	0.086
173	40.6841	39.09611	0.132
174	40.45544	39.48919	0.091
175	40.36191	39.57222	0.101
176	40.3329	39.51873	0.157
177	40.31698	39.48192	0.129
178	40.31324	39.4335	0.137
179	40.32698	39.51923	0.15
180	40.27543	39.43172	0.135
181	40.25722	39.47387	0.086

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
182	40.27414	39.52076	0.086
183	40.28406	39.49394	0.094
184	40.14281	39.42488	0.08
185	40.14249	39.39993	0.082
186	40.14756	39.38833	0.088
187	40.15176	39.37965	0.07
188	40.18958	39.32294	0.091
189	40.20865	39.33696	0.097
190	40.14223	39.22074	0.085
191	40.1898	39.32131	0.073
192	40.15816	39.35323	0.076
193	40.17262	39.32761	0.097
194	40.13136	39.36974	0.077
195	40.1271	39.33392	0.073
196	40.13694	39.3143	0.085
197	40.11576	39.29795	0.131
198	40.09671	39.27107	0.15
199	40.08886	39.2522	0.09
200	40.12142	39.23126	0.077
201	40.12651	39.22583	0.087
202	40.02124	39.12387	0.09
203	40.01003	39.1201	0.097
204	40.01202	39.11013	0.094
205	39.58138	39.24131	0.076
206	40.04068	39.11151	0.084
207	40.13184	39.21815	0.083
208	40.15473	39.20959	0.078
209	40.17194	39.1744	0.083
210	40.17647	39.13262	0.085
211	40.17657	39.09076	0.083
212	40.16545	39.07876	0.084
213	40.14896	39.07371	0.063
214	40.11463	39.0816	0.086
215	40.09331	39.06505	0.16
216	40.08149	39.04272	0.068
217	40.07003	39.18008	0.072

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
218	40.10705	39.04745	0.076
219	40.12878	39.032	0.076
220	40.14408	39.03902	0.075
221	40.1678	39.00476	0.053
222	40.06398	38.58183	0.084
223	40.04542	38.57525	0.092
224	40.09069	38.58417	0.08
225	40.08563	38.56095	0.076
226	40.11277	38.59388	0.077
227	40.13164	39.01062	0.067
228	40.21734	38.98676	0.056
229	40.16	39.01648	0.051
230	40.1318	38.96355	0.088
231	40.13844	38.95008	0.085
232	40.16868	38.95555	0.078
233	40.16912	38.98813	0.043
234	40.11223	39.021	0.064
235	40.17857	39.11338	0.058
236	40.19565	39.13415	0.056
237	40.242	39.17581	0.092
238	40.21556	39.15486	0.08
239	40.12115	39.09509	0.06
240	40.20893	39.20492	0.058
241	40.22415	39.21115	0.055
242	40.21653	39.24638	0.078
243	40.2238	39.2811	0.094
244	40.1323	39.18138	0.101
245	40.25418	39.28769	0.073
246	40.26081	39.29231	0.075
247	40.3056	39.28577	0.23
248	40.30253	39.28779	0.184
249	40.30271	39.254	0.2
250	40.34248	39.2213	0.179
251	40.38784	39.22651	0.09
252	40.40883	39.26995	0.06
253	40.41404	39.27046	0.065

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
254	40.42448	39.29282	0.102
255	40.43943	39.34337	0.085
256	40.41663	39.35218	0.141
257	40.46789	39.3435	0.24
258	40.46222	39.36184	0.1
259	40.44249	39.33122	0.113
260	40.47673	39.37222	0.132
261	40.49598	39.37273	0.138
262	40.46191	39.4703	0.115
263	40.46633	39.48229	0.11
264	40.4682	39.47736	0.057
265	40.475	39.48341	0.09
266	40.48013	39.48195	0.089
267	40.48275	39.48872	0.12
268	40.48913	39.49338	0.115
269	40.49333	39.51153	0.075
270	40.49188	39.52241	0.09
271	40.49791	39.50456	0.08
272	40.498	39.49508	0.095
273	40.4958	39.47708	0.096
274	40.50006	39.4704	0.118
275	40.50783	39.47481	0.12
276	40.50234	39.47626	0.124
277	40.51668	39.35913	0.13
278	40.49147	39.37441	0.122
279	40.49633	39.393	0.111
280	40.38663	39.33648	0.195
281	40.36087	39.326	0.145
282	40.346	39.31212	0.164
283	40.34163	39.32113	0.16
284	40.42571	39.3513	0.31
285	40.403	39.363	0.255
286	40.41738	39.37787	0.11
287	40.42462	39.38082	0.265
288	40.4323	39.38044	0.405
289	40.44461	39.38577	0.095

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
290	40.44914	39.41873	0.077
291	40.45149	39.42463	0.143
292	40.46026	39.4322	0.174
293	40.462	39.44453	0.112
294	40.45267	39.45449	0.078
295	40.4536	39.45811	0.094
296	40.45896	39.46269	0.189
297	40.45936	39.48513	0.16
298	40.49902	39.50306	0.078
299	40.43449	39.5082	0.176
300	40.40971	39.4899	0.237
301	40.40413	39.47056	0.213
302	40.41851	39.61812	0.058
303	40.42357	39.61811	0.025
304	40.43896	39.63322	0.023
305	40.43896	39.60163	0.066
306	40.44897	39.60107	0.15
307	40.45794	39.59615	0.088
308	40.74642	39.15715	0.067
309	40.63472	38.93253	0.079
310	40.282	39.35009	0.082
311	40.72969	39.11003	0.068
312	40.69771	38.38087	0.076
313	40.55796	39.03599	0.07
314	40.63424	38.9799	0.085
315	40.57366	39.02926	0.094
316	40.52888	39.09433	0.09
317	40.54001	38.8767	0.075
318	40.60956	39.0674	0.088
319	40.45027	39.15939	0.072
320	40.68584	39.14144	0.076
321	39.92751	39.7674	0.086
322	39.88039	39.6642	0.097
323	39.92976	39.76515	0.09
324	39.97687	39.67541	0.092
325	40.21245	39.84817	0.076

Table 3 (continued)

Samples No.	Latitude (North)	Longitude (East)	Effective dose rate (μsv/h)
326	40.32911	39.85939	0.067
327	40.30668	39.74048	0.069
328	40.41886	39.88182	0.078
329	40.49065	39.98054	0.066
330	40.48617	40.04336	0.086
331	40.58264	40.08823	0.078
332	40.52655	40.11291	0.071
333	40.60059	39.80554	0.065
334	40.64322	39.84368	0.072
335	40.69033	39.83022	0.086
336	40.70828	39.86836	0.054
337	40.5086	39.69336	0.065
338	40.47943	39.64625	0.068

^{40}K, ^{137}Cs, ^{226}Ra and ^{232}Th, gross alpha and gross beta in water readings and air effective dose values obtained from the measurements in the study area are the coordinates of the point and the value in this coordinate is measured in UTM ED50 projection system transferred to the numerical environment. The minimum curvature superficial grid maps were generated for each reading value of these numerically expressed readings and some anomaly regions were determined. These anomaly areas are overlapped with the geology map of the drawing editor taken over the MTA (http://yerbilimleri.mta.gov.tr/anayfa.aspx) and overlapped and compared on a similar scale as ^{40}K, ^{137}Cs, ^{226}Ra and ^{232}Th values for grid anomalies, especially for ^{40}K anomaly.[41–44]

Conclusion

This research aimed to assess radioactivity levels of gross alpha and beta activity in the drinking waters, natural (^{226}Ra, ^{232}Th and ^{40}K) and artificial (^{137}Cs) radionuclides in soil samples and the coordinates and measurement values of natural radioactivity measurements made in the air, Gumushane province, Turkey. The aggregate Alpha–Beta analysis of collected samples from local water sources have been done at The Küçükçekmece Atom Energy Institute of Turkey in İstanbul. It has been found that radioactivity levels in Gümüşhane drinking water, are below the limits of constituting a health hazard for the public.

The activity concentrations of natural (^{226}Ra, ^{232}Th and ^{40}K) and artificial (^{137}Cs) radionuclides in 62 soil samples were determined by using Gama-ray spectroscopy present in Çekmece Nuclear Research and Training Center (ÇNAEM). The measured activity concentrations were further evaluated for mean radium equivalent activity (Ra_{eq}), gamma absorbed dose rates in air (D), annual effective dose rates (AEDR) and external hazard index(Hex). Obtained values show that the mean radium equivalent activity (Ra_{eq}) were from 7.4 to 434 Bq/kg. The gamma absorbed dose rates in air were in the range of 3.7–202.9 nGy h^{-1}, with an arithmetic mean of 60.4 nGy h^{-1}, while the annual effective dose rates were determined to be in the range of 4.7–248.8 μSv y^{-1}. The calculated values of external hazard index (Hex) for the soil samples in the study area were in the range of 0.02–1.19. The activity concentrations of radionuclides in soil samples were compared with the international data reported by UNSCEAR, 2000. It was observed that the obtained activity concentration results in soil samples were below the mean values for Turkey.

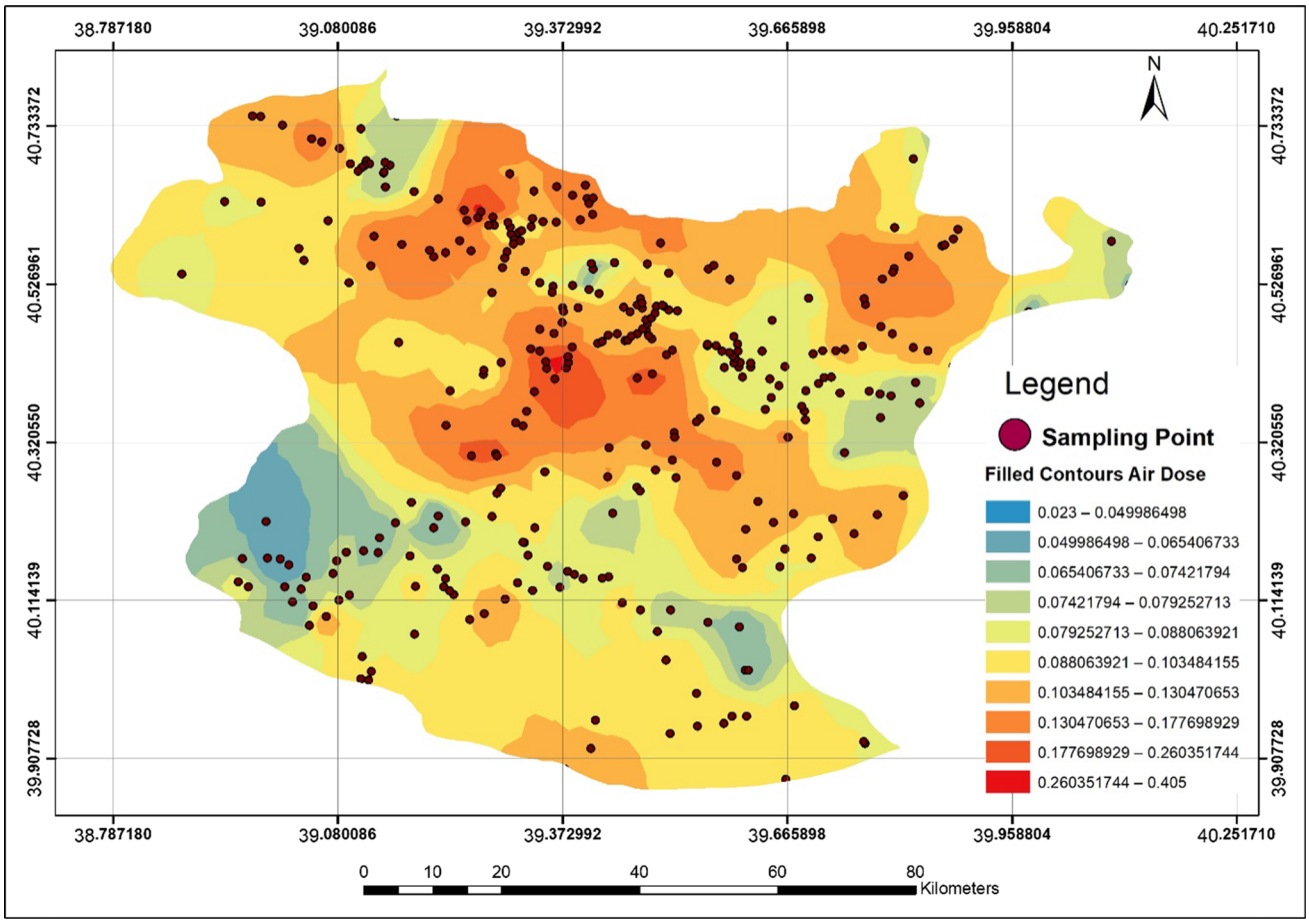

Fig. 8 Iso-dose map of natural gamma radiation in Gümüşhane province air (μSv/h)

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References

1. IAEA (International Atomic Energy Agency) (1989) Measurement of radionuclides in food and the environmental. Technical reports series 295, Vienna
2. Higgy RH, Pimpl M (1998) Natural and man-made radioactivity in soils and plants around the research reactor of Inshass. Appl Radiat Isot 49(12):1709–1712. https://doi.org/10.1016/S0969-8043(98)00009-8
3. Miah FK, Roy S, Touchiduzzaman M, Alam B (1998) Distribution of radionuclides in soil samples in and around Dhaka city. Appl Radiat Isot 49(1–2):133–137. https://doi.org/10.1016/S0969-8043(97)00232-7
4. Shenber MA (1997) Measurement of natural radioactivity levels in soil in Tripoli. Appl Radiat Isot 48(1):147–148. https://doi.org/10.1016/S0969-8043(96)00065-6
5. Karahan G, Bayulken A (2000) Assessment of gamma dose rates around Istanbul (Turkey). J Environ Radioact 47(2):213–221. https://doi.org/10.1016/S0265-931X(99)00034-X
6. Al-Masri MS, Amin Y, Hassan M, Ibrahim S (2006) External gamma-radiation dose to Syrian population based on the measurement of gamma-emitters in soils. J Radioanal Nucl Chem 267(2):337–343. https://doi.org/10.1007/s10967-006-0052-6
7. Kharisat K (2010) Measurement of Some alpha-emitters concentrations in soil and vegetable samples in Tafila District. Ms.Sc. thesis, Physics Department, Yarmouk University, Irbid-Jordan
8. Abu Haija O (2012) Determination of natural radionuclides concentrations in surface soil in Tafila/Jordan. Mod Appl Sci 6:87–90. https://doi.org/10.5539/mas.v6n3p87
9. Davis SN, DeWiest RJM (1966) Hydrogeology. Wiley, New York, NY
10. Sahinci A (1991) Geochemistry of natural waters. Reform Printing Office, Izmir, p 548 **(in Turkish)**
11. Gören E (2011) Determination of tritium activity at drinking waters in Adana. Master thesis, Cukurova University, Institute of Science and Technology, Adana
12. Gültekin F, Dilek R (2005) The trace element and radioactivity content of mineral water resources in Gümüşhane region. J Geol Eng 29(1):36–43
13. Damla N (2006) Gross alpha, gross beta and gamma activities in tap waters of Eastern Black Sea. Master thesis, Karadeniz technical University, Institute of Science and Technology, Trabzon, Turkey
14. Damla N, Cevik U, Karahan G, Kobya AI (2006) Gross α and β activities in tap waters in Eastern Black Sea region of Turkey. Chemosphere 62(6):957–960

15. Damla N, Cevik U, Karahan G, Kobya AI, Kocak M, Isık U (2009) Determination of gross α and β activities in waters from Batman, Turkey. Desalination 244(1–3):208–214
16. Kaya Ali, Karabidak Salih Mustafa, Kaya Selim (2016) Radioactivity measurement of natural water sources in the area of Bahçecik Village/Gümüşhane-Turkey. Gümüşhane Univ J Sci Technol Inst 6:13–22. https://doi.org/10.17714/gufbed.2016.06.002
17. Osmond JK, Ivanovich M (1992) Equilibrium-series disequilibrium. Applications to the earth marine and environmental sciences. Clarendon Press, Oxford
18. Blanchard RL, Hahne RM, Kahn B, McCurdy D, Mellor RA, Moore WS, Whittaker E (1985) Radiological sampling and analytical methods for National Primary Drinking Water Regulations. Health Phys 48(5):587–600
19. Agbalagba Ezekiel O, Avwiri Gregory O, Chadumoren Yehuwdah E (2013) Gross α and β activity concentration and estimation of adults and infants dose intake in surface and ground water of ten oil fields environment in Western Niger Delta of Nigeria. J Appl Sci Environ Manag 17(2):267–277
20. Yeşilkanat CM, Kobya Y (2015) Determination and mapping the spatial distribution of radioactivity of natural spring water in the Eastern Black Sea Region by using artificial neural network method. Environ Monit Assess 187(9):589. https://doi.org/10.1007/s10661-015-4811-0
21. Bakaç M (1998). The examination of the Gediz River and its surroundings by the factor analysis method determining the levels of radioactivity, major and trace element. Ph.D. thesis, Ege University, Institute of Science and Technology, Izmir, Turkey
22. Banzi FP, Msaki P, Makundi IN (2002) A survey of background radiation dose rates and radioactivity in Tanzania. Health Phys 82(1):80–86
23. Sannappa J, Chandrashekara MS, Sathish LA, Paramesh L, Venkataramaiah P (2003) Study of background radiation dose in Mysore city, Karnataka State, India. Radiat Meas 37(1):55–65
24. Ramli AT, Hussein AWM, Wood AK (2005) Environmental 238U and 232Th concentration measurements in an area of high-level natural background radiation at Palong, Johor, Malaysia. J Environ Radioact 80(3):287–304
25. Değerlier M (2007) Determination of environmental natural radioactivity of Adana and the annual effective dose equivalent due to natural radiation. Ph.D. thesis, Çukurova University, Institute of Natural and Applied Sciences, Adana, Turkey
26. Ahmed Nour Khalifa (2004) Natural radioactivity of ground and drinking water in some areas of upper Egypt. Turk J Eng Environ Sci 28(6):345–354
27. Topuz G, Altherr R, Schwarz WH, Dokuz A, Meyer HP (2007) Variscan amphibolite-facies rocks from the Kurtoğlu metamorphic complex (Gümüşhane area, Eastern Pontides, Turkey). Int J Earth Sci 96(5):861–873. https://doi.org/10.1007/s00531-006-0138-y
28. EPA U.S. Environmental Protection Agency (1980) Prescribed procedures for measurement of radioactivity in drinking water. In: Gross alpha and gross betaradioactivity in drinking water, Method 900.0. EPA 600/4-80-032
29. Turhan Ş, Özçıtak E, Taşkın H, Varinlioğlu A (2013) Determination of natural radioactivity by gross alpha and beta measurements in ground water samples. Water Res 47(9):3103–3108
30. Ataksor B (2002). A new investigation on pollution of basin surface water gross alpha and gross beta radioactivity determination and comparable evaluation with receptor model. Ph.D. thesis, ITU. Nuclear Energy Institute, Istanbul, Turkey
31. Kayakökü H, Doğru M (2020) Radiological hazard assessment of natural radionuclides and heavy metal pollution in deep mud samples of Van Lake, Turkey. J Radioanal Nucl Chem 324:1339–1350. https://doi.org/10.1007/s10967-020-07184-8
32. Kulahci F, Dogru M (2006) Physical and chemical investigation of water and sediment of the Keban Dam Lake, Turkey: Part 2: distribution of radioactivity, heavy metals and major elements. J Radioanal Nucl Chem 268(3):529–537
33. Vu NB, Huynh NPT (2018) Gross alpha and beta radioactivity in food crops and surface soil from Ho Chi Minh City, Vietnam. J Radioanal Nucl Chem 315(1):65–73
34. TAEK (2000) Turkish Atomic Energy Authority, the methods sampling, measurement and analysis in impression of environmental radioactivity Cekmece Nuclear Research and Training Center, Istanbul (Turkey) Report Number: INIS-TR-0043
35. United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR) (2000) Sources and effects of ionizing radiation (Report to general assembly, Annex A and B). United Nations, New York, NY
36. Maden N, Çelik N, Akaryalı E, Öztürk S (2011) Gumushane Province natural source radiation measurement report. Gumushane University, Turkey
37. Gezer F (2011) Determination of natural radioactivity at phosphogypsum. Master thesis, Cukurova University, Institute of Science and Technology, Adana, Turkey
38. Yalcin MG, Unal S (2018) Natural radioactivity levels and associated radiation hazards in ophiolites around Tekirova, Kemer, and Kumluca Touristic Regions in Antalya, Turkey. J Radioanal Nucl Chem 316(1):321–330
39. Abbasi A, Kurnaz A, Turhan Ş et al (2020) Radiation hazards and natural radioactivity levels in surface soil samples from dwelling areas of North Cyprus. J Radioanal Nucl Chem 324:203–210. https://doi.org/10.1007/s10967-020-07069-w
40. Şahin K, Kaygusuz A (2016) Petrographical, geochemical and petrological features of Eocene volcanic rocks in the Mescitli (Torul/Gümüşhane) and surrounding area. Gümüşhane Univ J Sci Technol Inst 6:89–116. https://doi.org/10.17714/gufbed.2016.06.010
41. TSE 266 (2005) Waters, 2005, water for human consumption purposes. Turkish Standards Institute, Ankara
42. World Health Organization (1978) Radiological examination of drinking water. WHO, Copenhagen, Agbalagba, Avwiri and Chadumoren, it was taken 2013
43. NCRP 50 (1978) National Council Radiation Protection and Measurements. Environmental radiation measurements, NCRP Report No. 50
44. NCRP 58 (1985) National Council on Radiation Protection and Measurements. A handbook of radioactivity measurements, NCRP Report No. 50