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RADIOECOLOGICAL CHARACTERIZATION OF THE TERRITROY OF KAZBEGI MUNICIPALITY

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The monograph examines the radioecological condition of the territory of the Kazbegi municipality. The results of studies of the radionuclide composition of soil and rock samples taken on the territory of the municipality, the concentration of activity of radioactive radon gas in soil gas, the power of the ambient equivalent of gamma radiation dose are presented. The analysis of the obtained results is performed. A comparison is made with the literature data from different regions of the world.

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C O N T E N T

INTRODUCTION

The human environment contains natural sources of radiation. Soil, rocks, water, atmosphere, and space objects have natural radioactivity. The primary source of natural radiation in many cases is solar radiation and the energy of decay of some elements of the earth's crust. The natural radiation level is not the same everywhere. The radiation level of the territory high in the mountains exceeds that at the level of the world ocean by almost five times; there are also zones of the earth's surface where radiation is noticeably higher due to the location of radioactive substances in the bowels of the earth (in particular, uranium-containing rocks).

In addition to natural sources of radiation, there are sources of technogenic (man-made) radiation, such as nuclear power plants, nuclear test zones, sites of burial and leaks of nuclear fuel, etc.

The study of natural and technogenic radioactivity in various environmental objects is one of the urgent problems of ecology. Natural radioactivity in the environment is caused by radionuclides of three families - Th-232, U-238 and U-235, as well as K-40, which are so-called alpha-, beta- or gamma-emitters. Among natural sources of radiation, the most significant is the invisible, tasteless and odorless heavy gas (7.5 times heavier than air) radon (Rn-222). Radon, together with its daughter decay products, is responsible for about three quarters of the annual individual effective radiation dose received by the population from terrestrial radiation sources, and about half of this dose from all natural radiation sources. Among technogenic radionuclides, the long-lived radionuclide Cs-137 (as well as Sr-90) is the most common.

Studies of the radioactivity level of a particular territory are conducted all over the world. In Georgia, studies of the radioactivity of various environmental objects have been conducted in the past and were mainly stimulated by the accident at the Chernobyl nuclear power plant in 1986.

In the present work, a study of natural and technogenic radioactivity was conducted in the part of the territory of the Kazbegi municipality, directly adjacent to the border of Georgia with the Russian Federation. The aim of the work was to establish the radionuclide composition and background concentrations of radionuclides in various soil and geological structures in the study area, to study the level of gamma radioactivity, as well as to assess the corresponding radiological risk to the local population and tourists.

CHAPTER 1

1. MATERIALS AND METHODS

1.1. Study area

Kazbegi municipality is part of the Mtskheta-Mtianeti region. The municipality is located entirely in the mountainous part of Georgia. The height above sea level varies from 1,700 m to 5,000 m. The area of the municipality is 1081.7 km^2. The municipality borders the Russian Federation in the northern part.

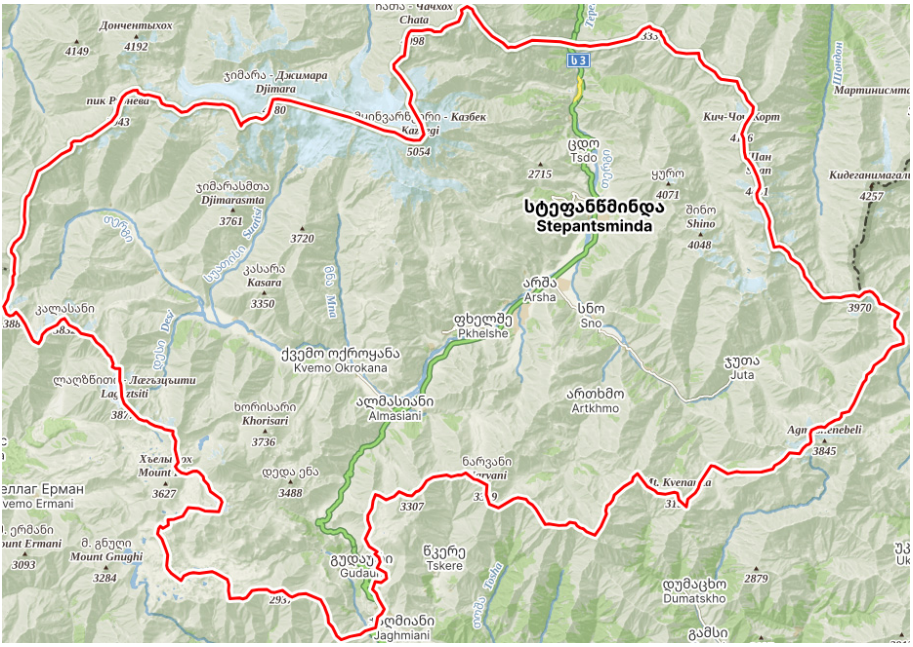


Figure 1. Map of the Kazbegi municipality

The main orographic unit of the territory is the Main Caucasian Ridge. The relief of the municipality is mountainous in nature – mostly rocky and difficult to access. Erosive, volcanic and glacial landforms are developed. Karst rocks are found sporadically.

Figure 2. Some of the studied areas of the municipality

Most of the territory is occupied by mountain meadow and primitive soils. Mountain-forest soils are found in the gorge of the River Terek and some of its tributaries. Alluvial soils are also found. In high-altitude areas, the forest cover is devoid of soil.

Various works were carried out on the studied territory aimed at achieving the main task set in the project – the study of the radioecological condition of the territory of the municipality.

1.1.1. Control points and samples

Table 1 shows a general list of control points in the studied area, their brief description, and geographical coordinates. The Table also shows the operation performed at this control point, including:

- Soil – soil sampling, and sample number;
- Rock – rock sampling, and sample number;
- Soil radon – measurement of radon concentration in soil air;
- Doz – measurement of the ambient dose equivalent rate of gamma radiation.

Table 1. List of control points

#	CP	Lt(N); Ln(E)	Description of CP	Operation	SN
1	Kz-1	42.7332; 44.6319	Mtavarangelozi Monastery complex	Rock	416-R
2	Kz-2	"-"	"-"	Doz	
3	Kz-3	42.7364; 44.6355	"-"	Soil	394-S
4	Kz-4	42.7351; 44.6353	"-"	Rock	401-R
5	Kz-5	42.6670; 44.62986	Stepantsminda-Larsi road, Chkhere River gorge	Rock	398-R
6	Kz-6	42.6641; 44.6410	Stepantsminda-Larsi road, the confluence of the rivers Terek and Chkhere	Soil	393-S
7	Kz-7	42.7137; 44.6245	The village Gveleti	Soil radon	
8	Kz-8	"-"	"-"	Doz	
9	Kz-9	"-"	"-"	Soil	428-S
10	Kz-10	42.6937; 44.6410	Terek River valley	Rock	415-R
11	Kz-11	"-"	"-"	Doz	
12	Kz-12	42.6822; 44.6344	Stepantsminda-Larsi road, the bridge near village Tsdo	Soil	438-S
13	Kz-13	"-"	"-"	Doz	
14	Kz-14	42.6588; 44.6350	The bridge over the Chkhere River, near the ascent to the Gergeti Trinity Church	Soil	426-S
15	Kz-15	"-"	"-"	Soil radon	
16	Kz-16	"-"	"-"	Doz	
17	Kz-17	42.6420; 44.6364	Tbilisi-Stepantsminda road, near the entrance to Stepantsminda	Soil	430-S
18	Kz-18	"-"	"-"	Soil radon	
19	Kz-19	"-"	"-"	Doz	
20	Kz-20	"-"	"-"	Rock	414-R
21	Kz-21	42.6381; 44.6352	Near the confluence of the rivers Terek and Snostskali	Rock	399–R
22	Kz-22	42.6030; 44.5820	The village Sioni	Soil	435-S
23	Kz-23	"-"	"-"	Soil radon	
24	Kz-24	"-"	"-"	Doz	
25	Kz-25	42.5765; 44.6807	The village Karkucha	Soil radon	
26	Kz-26	"-"	"-"	Doz	
27	Kz-27	"-"	"-"	Soil	439-S
28	Kz-28	42.5595; 44.7022	Villagrs Karkucha-Juta road	Rock	409-R
29	Kz-29	"-"	"-"	Doz	

30	Kz-30	42.5948; 44.6697	The village Akhaltsikhe	Soil	427-S
31	Kz-31	“-“	“-“	Rock	413-R
32	Kz-32	“-“	“-“	Doz	
33	Kz-33	42.6035; 44.5682	The village Goristsikhe	Rock	418-R
34	Kz-34	“-“	“-“	Doz	
35	Kz-35	“-“	“-“	Soil	423-S
36	Kz-36	“-“	“-“	Rock	420-R
37	Kz-37	42.5719; 44.5240	The village Kobi	Rock	417-R
38	Kz-38	“-“	“-“	Doz	
39	Kz-39	42.5604; 44.5121	“-“	Rock	402-R
40	Kz-40	42.56048; 44.5120	“-“	Soil	395-S
41	Kz-41	42.5715; 44.5229	The village Kanobi	Soil	422-S
42	Kz-42	42.5849; 44.5535	“-“	Rock	403-R
43	Kz-43	“-“	“-“	Doz	
44	Kz-44	42.6618; 44.6467	Turn to the village Pansheti	Soil	424-S
45	Kz-45	“-“	“-“	Soil radon	
46	Kz-46	42.6360; 44.6112	The village Pansheti	Soil	429-S
47	Kz-47	“-“	“-“	Doz	
48	Kz-48	42.5516; 44.4949	Surroundings of Kobi village	Soil	432-S
49	Kz-49	“-“	“-“	Doz	
50	Kz-50	42.5516; 44.4944	“-“	Rock	406-R
51	Kz-51	“-“	“-“	Doz	
52	Kz-52	42.5322; 44.4721	Cross Pass Travertine	Soil	437-S
53	Kz-53	42.5380; 44.4763	“-“	Doz	
54	Kz-54	“-“	“-“	Rock	411-R
55	Kz-55	42.6236; 44.6097	Near the entrance to the village Arsha	Rock	397-R
56	Kz-56	42.6235; 44.6097	“-“	Soil	396-S
57	Kz-57	42. 6230; 44.5983	The village Arsha, Gaiboteni	Soil	436-S
58	Kz-58	“-“	“-“	Doz	
59	Kz-59	“-“	“-“	Rock	405-R
60	Kz-60	“-“	“-“	Soil radon	
61	Kz-61	42.6237; 44.6098	Surroundings of Arsha village	Rock	404-R
62	Kz-62	“-“	“-“	Doz	
63	Kz-63	“-“	“-“	Soil	421-S
64	Kz-64	42.6099; 44.5740	The village Tkarsheti	Rock	400-R
65	Kz-65	42.6582; 44.6229	Gergeti Trinity Church	Soil	434-S
66	Kz-66	“-“	“-“	Rock	412-R
67	Kz-67	“-“	“-“	Doz	
68	Kz-68	42.6575; 44.6376	The village Gergeti	Soil	425-S
69	Kz-69	“-“	“-“	Rock	410-R
70	Kz-70	“-“	“-“	Doz	
71	Kz-71	42.5134; 44.4622	Cross Pass	Soil	433-S
72	Kz-72	“-“	“-“	Doz	
73	Kz-73	“-“	“-“	Soil radon	
74	Kz-74	42.5000; 44.4836	Panorama Gudauri	Doz	
75	Kz-75	“-“	“-“	Rock	407-R
76	Kz-76	42.4766; 44.4777	The village Gudauri	Rock	408-R
77	Kz-77	“-“	“-“	Soil	431-S

Figure 3. Near control points Kz-52, Kz-53, Kz-54

1.2. Sampling and analysis

1.2.1. Sampling and sample preparation

The control sites for soil sampling were laid on the most undisturbed soils. Soil samples were taken directly into plastic containers (2.0 l in volume). After drying in the laboratory, the samples were crushed and sieved in a sieve with a cell size of 1 mm in order to homogenize them.

Rock samples were taken from surface rock outcrops directly into plastic containers (up to 2.0 liters in volume). After drying in the laboratory, the samples were split into pieces up to 40 mm in size and then crushed on a special BB 50 crusher (Retcsh GmbH, Germany) to a size of about 1 mm.

Figure 4. Rock sampling

After that, the soil and rock samples were dried at a temperature of 105°C to a constant weight. Then the weight of the samples was measured and their specific gravity was determined. These values were used to describe the geometry of the samples when measuring the activity of gamma radiation. The samples were sealed in a Marinelli vessel (volume 1 liter) and stored for more than 4 weeks to achieve a secular equilibrium between Ra-226 and Rn-222.

Figure 5. Various operations of rock sample preparation

1.2.2. Measurements

1.2.2.1.Gamma radiation activity

Figure 6. Gamma-spectrometer GC2020

Measurements of the radionuclide content of the studied samples and the activity concentration of radionuclides were carried out using a Canberra GC2020 gamma-spectrometer with a semiconductor germanium detector with a relative efficiency of 24%. The acquisition time for gamma spectra was 48 hours. The Genie-2000 S500 software with additional modules was used for the analysis, in particular, S506, an Interactive Fit Program. This program was used to "decompose" the interference peak in the 186 keV region in all spectra (in this region, the program identifies one peak resulting from the interference of two closely spaced peaks U-235 (185.715 keV) and Ra-226 (186.211 keV)). Using the S506C program, the spectral curve is mathematically processed, as a result of which two Gaussian peaks with energies corresponding to U-235 and Ra-226 are created in this region. When programmatically identifying peaks and calculating the concentration of activity, the tolerance value was set in such a way that only U-235 was compared to the low–energy peak, and only Ra-226 to the high-energy peak. As the results showed, in particular for Ra-226, the error in determining its activity concentration was mainly in the range of 9 - 24%. His activity was compared with the activity of his daughters Pb–214 and Bi-214, the error in determining which lay in the range from 3 to 9%. The obtained activity values of Ra-226, Pb-214 and Bi-214 differed little from each other. Thus, it can be considered that the error in determining the concentration of Ra-226 in this way is quite satisfactory, and this method was also used to determine the activity concentration of U-235 along the 185.715 keV line. The obtained values of U-235 activity were compared with the values of U-238 activity (which was determined by the Th-234 - 63.3 keV line with an error in the range of 6.3 - 14%). The value of the ratio of their activities (U-238/U-235 = 21.7 [1]) was used as a criterion. With large deviations from this value (more than 10%), the

185.715 keV line (as well as the 63.3 keV line) was reanalyzed using the S506 program. (In some cases, in low-activity samples, the activity of Ra-226 was refined by the average activity of Pb-214 and Bi-214 and the resulting value was taken into account in the final assessment activity values U-235). To determine the activity of Th-232, the average values for Ac-228, Ra-224, Pb-212, Bi-212 were used, the errors of which ranged from 1.4 to 7.0%. The activity ratios U-238/Th-232 (which for closed systems is assumed to be 0.81 [2, 3]), Ra-226/U-238 and Pb-210/Ra-226 (equilibrium value 1.00) were also determined, which are used to evaluate the mechanism of various geochemical processes. In the studied soil samples, "superequilibrium" (allochthonous) Pb-210 was often observed, the value of which was determined by the difference between the measured activity values of Pb-210 and Ra-226 [2].

To account for the effect of the matrix content, based on the literature data, the chemical content of soil samples [4] and rocks [5] were established, which were then used in special software (LabSOCS) for efficiency calibration in calculating the activity concentration. The LabSOCS system allows you to create calibrations based on the effectiveness of laboratory quality without the use of radioactive calibration sources. A special library containing lines of 41 radionuclides and other specific sources (351 lines in total) was used to identify radionuclides. The NuDat database was used to compile the library [6].

To assess the potential radiation risk of terrestrial radioactivity for the population living in the studied region, various indicators were calculated.

To assess the radiological hazard, the radium equivalent activity of Ra_{eq} (Bq/kg) and the annual effective dose of AEDE (mSv/y) were calculated; the calculation was carried out according to the formulas [7]:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.07A_K \quad (1)$$

where A_U, A_{Th}, and A_K are the activity concentration (Bq/kg) of U-238, Th-232, and K-40, respectively;

$$AEDE = D \times N_h \times k_1 \times k_2 \quad (2)$$

where N_h is the number of hours per year (=8760 h), k_1 is the conversion factor of the effective dose rate into the absorbed dose rate in the air for adults, 0.7 Sv/Gy, k_2 is the outdoor coefficient (the proportion of time spent outdoors) which is 0.2, D is the absorbed dose rate (nGy/h):

$$D = k_U A_U + k_{Th} A_{Th} + k_K A_K \quad (3)$$

where k_U, k_{Th}, k_K are the so–called dose coefficients equal to 0.462, 0.604 and 0.0417, respectively.

To characterize the samples according to the degree of radioactivity, taking into account the accepted limit value of Ra_{eq} - 370 Bq/kg (equivalent to a dose of gamma radiation of 1.5 μSv/y) [8] several groups of samples were identified in terms of equivalent activity, in particular:

- group 1 – non-radioactive samples with an activity of no more than 30 Bq/kg;
- group 2 – with low radioactivity in the range from 30 to 100 Bq/kg;
- group 3 – with average radioactivity in the range from 100 to 300 Bq/kg;
- group 4 – samples with increased radioactivity in the range from 300 to 1000 Bq/kg.

Calculations of other indicators were also carried out to assess the radiation hazard, in particular:

- External hazard index (H_{ex}) is a widely used hazard index which represents the external exposure, and который рассчитывался по формуле:

$$H_{ex} = (A_U/370) + (A_{Th}/259) + (A_K/4810) \quad (4)$$

- Internal hazard index (H_{in}): in addition to external hazard index, radon and its short-lived products are also hazardous to the respiratory organs; the internal exposure to radon and its daughter progenies is quantified by the internal hazard index H_{in}, which is given by the equation:

$$H_{in} = (A_U/185) + (A_{Th}/259) + (A_K/4810) \quad (5)$$

The values of the indices (H_{ex}, H_{in}) must be less than unity for the radiation hazard to be negligible [9].

1.2.2.2. Soil gas radon

Figure 7. Electronic radon detector RAD7

Radon content in soil air was measured using an electronic radon detector RAD7 (Durridge Co., USA). Previously, a hole with a diameter of about 10 cm to a depth of 60-80 cm is made in the place selected for measurement using a hand auger, into which a steel probe is lowered. Before starting the measurement, the prepared well is carefully sealed with earth around the probe to prevent fresh air from entering down the outside of the probe. The probe is then connected to the detectors using a plastic tubular hose. The principle of the measurement method is to supply a sample of soil air to the measuring chamber of the detector to measure the radon content. Soil gas is piped into the internal storage chamber of the measuring device during a 5-minute pumping phase, during which an electrostatic collection of alpha emitters with spectral analysis takes place. The device waits for another 5 minutes, and then counts down four 5-minute cycles. The Sniff mode selected for measurement covers the energy range from 5.40 to 6.40 MeV, showing the total number of alpha particles with energy of 6.00 MeV formed during the decay of Po-218 (daughter element of Rn-222). Thus, alpha radiation with energy of 6.00 MeV, caused by the decay of Po-218, makes it possible to obtain the activity of Rn-222. The total measurement time is 30 minutes. At the end of the half-hour period, the detector prints a summary of the measurement, including the average radon concentration in the soil gas over four 5-minute measurement cycles. This method provides fast readings and uses the least amount of soil gas. The measurement results in Bq/m^3 units are determined by the average value of the four measurements with an error of ±5%. The measurement results were processed using the Capture software.

Figure 8. The process of measuring radon concentration in soil air

1.2.2.3. Ambient dose equivalent rate of gamma-radiation

The measurement of the ambient dose equivalent rate of gamma radiation H*(10) (gamma background) of the studied area was carried out using a dosimeter-radiometer PM-1403. This device allows measuring power in the range of 0.1 mSv/h - 10 Sv/h in the range of recorded gamma radiation energies of 0.03 – 3 MeV. The dose rate measurement is based on measuring the average pulse counting rate from Geiger-Muller counters, which is proportional to the measured dose rate. The counting rate is converted into the dose rate.

Dose rate measurements were carried out at soil and rock sampling sites, as well as measurements of radon concentration in soil air. The measurements were carried out at a height of 1 m above the earth's surface.

The GPS module built into the dosimeter provided the determination of the geographical coordinates of the control points.

Figure 9. Measurement of the gamma-background level

CHAPTER 2

2. RESULTS AND DISCUSSION

2.1. Activity concentration

2.1.1. Soil activity

Figure 10 shows a typical gamma spectrum of a soil sample[1]. According to the results of the analysis of gamma spectra up to 22 radionuclides are identified in soil samples - family Th–232 (Ac-228, Th-228, Ra-224, Pb-212, Bi-212, Tl-208), family U-238 (Th-234, Pa-234, Th-230, Ra-226, Pb-214, Bi-214, Pb-210), family U-235 (U-235, Th-231, Th-227, Ra-223, Rn-219, Pb-211), separate radionuclides Be-7, K-40, Cs-137 (also some specific lines are identified that arise as a result of the interaction of cosmic rays with the material of detector or sample).

The results of measuring the activity concentration of the main radionuclides for the studied samples, the values of radium equivalent activity (Ra_{eq}), dose rate (D) and annual effective dose (AEDE), the ratios of activity of various radionuclides, their average (av), minimum (mn) and maximum (mx) values are shown in Table 2 and Table 3.

As can be seen from Table 2, the activity of radionuclides of various families varied quite widely, in particular, the range of variation was 15.6 – 52.4 Bq/kg (average value 39.3 Bq/kg) for Th-232, 15.1 – 40.9 Bq/kg (average value 30.7 Bq/kg) for U-238, 0.91 – 2.54 Bq/kg (average value 1.75 Bq/kg) for U-235. In a number of samples, the activity of some radionuclides is below the minimum detectable activity (MDA). There is no significant difference between the values of the activity concentration for soil samples of different types.

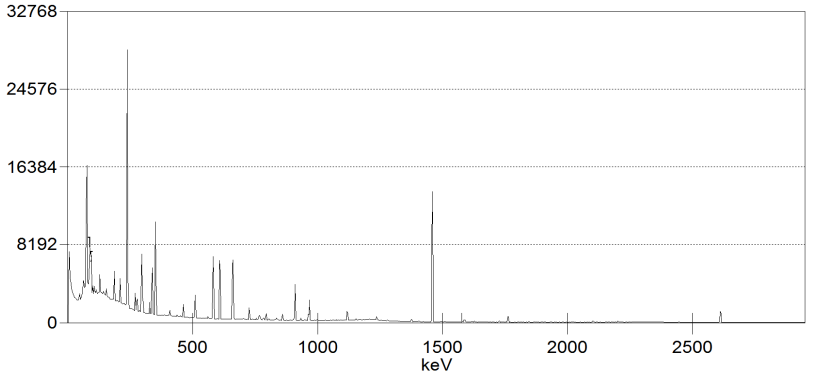


Figure 10. Gamma spectrum of the soil sample #396-S
(the values of the number of pulses recorded by the germanium detector of the gamma spectrometer are postponed along the vertical axis).

[1] The gamma spectra obtained for rock samples have a similar appearance.

The values of the activity concentration of the natural radionuclide K-40 range from 179 to 755 Bq/kg with an average value of 513 Bq/kg. Be-7 was recorded in 18 samples with an activity concentration in the range of 3.5 – 28.0 Bq/kg (average value 7.5 Bq/kg). Radionuclide Cs-137 was detected in almost all samples (concentration range 0.24 – 39.2 Bq/kg with an average value of 13.7 Bq/kg). The activity ratios of U-238/U-235 for five samples correspond (within 10%) to the value of 21.7 (accepted for natural objects), and for the remaining samples these values are less and are in the range of 13.6 – 19.4. The activity ratio of U-238/Th-232 deviate (more than 10%) from the average values 0.81 (for closed systems) both upward (to the value of 1.13) and downward (to 0.62). The activity ratios of Ra-226/U-238 for four samples correspond (within ±10%) to the equilibrium value (1.00), and for the remaining samples they are mostly less than the equilibrium value (up to 0.65), and in some cases higher than this value (up to 1.22). The activity ratios of Pb-210/Ra-226 in almost all samples, there is noticeably (more than 20%[2]) more than the equilibrium value (the highest value is 15.6). The main number of samples (91%) in terms of activity belongs to the group with medium radioactivity; a small number of samples (9%) belong to the group with low radioactivity.

Table 2. Activity concentration (A, Bq/kg) of radionuclides of the families Th-232, U-238, Ra-226, Pb-210, U-235, separate radionuclides Be-7, K-40 and Cs-137, their average (*av*), minimum (*mn*) and maximum (*mx*) values in soil samples

#	FN	CP	ST	A, Bq/kg									
				Th-232	U-238	Ra-226	Pb-214	Bi-214	Pb-210	U-235	Be-7	K-40	Cs-137
1	431-S	Kz-75	MMS	43.8	35.2	30.7	37.3	34.8	28.2	2.30	5.9	391	5.3
2	432-S	Kz-48	-"-	30.4	34.2	28.6	35.1	33.1	40.4	1.47	<M	479	6.3
3	433-S	Kz-70	-"-	44.6	40.5	42.1	39.0	36.4	32.9	2.54	7.2	519	3.8
4	437-S	Kz-52	-"-	39.1	31.8	26.1	29.7	27.8	98.4	1.78	6.3	511	13.9
5	439-S	Kz-27	-"-	50.8	33.8	41.5	30.2	28.2	419.0	1.43	28.0	609	6.8
6	435-S	Kz-22	MMB	37.3	26.6	17.5	28.6	26.3	84.8	1.88	5.4	511	2.7
7	393-S	Kz-6	MFM	33.2	25.8	22.1	24.8	23.3	150.1	1.90	<M	455	31.2
8	394-S	Kz-3	-"-	40.6	27.7	-	27.2	26.1	<M	1.44	-	484	0.24
9	395-S	Kz-40	-"-	21.9	20.2	13.1	19.3	18.0	204.4	0.98	<M	348	37.4
10	396-S	Kz-56	-"-	50.1	33.7	27.5	31.5	29.1	84.8	1.83	-	755	17.5
11	421-S	Kz-62	-"-	41.3	31.8	-	30.5	28.3	33.9	1.64	6.3	532	1.58
12	422-S	Kz-41	-"-	39.5	32.9	24.9	31.0	29.1	<M	2.11	4.7	491	<M
13	423-S	Kz-35	-"-	40.5	30.7	23.0	31.4	29.1	102.8	1.76	7.1	551	6.33
14	424-S	Kz-44	-"-	36.7	29.1	30.5	27.9	25.6	92.1	1.51	4.1	509	14.4
15	425-S	Kz-67	-"-	51.8	40.9	34.6	35.3	33.8	103.3	2.30	6.9	695	34.2
16	426-S	Kz-14	-"-	31.7	27.2	24.0	26.4	25.0	77.2	1.35	8.9	417	5.20
17	427-S	Kz-30	-"-	52.4	32.3	27.0	31.8	29.3	97.9	2.05	5.2	725	15.3

[2] The range of limits has been expanded, since the error of Pb-210 reached 20%.

18	428-S	Kz-9	-"-	40.7	29.3	20.3	30.7	28.7	136.2	1.93	3.5	581	25.3
19	429-S	Kz-46	-"-	44.0	33.0	26.3	31.0	28.8	43.6	1.84	5.2	618	6.44
20	430-S	Kz-17	-"-	45.6	32.3	28.0	32.8	31.1	177.3	1.90	6.3	579	39.2
21	434-S	Kz-64	-"-	40.8	35.2	33.9	35.5	33.5	58.4	1.81	6.9	450	21.2
22	436-S	Kz-57	-"-	15.6	15.1	12.1	16.1	15.1	32.1	0.91	11.0	179	1.95
23	438-S	Kz-12	-"-	32.4	26.1	18.4	25.8	24.5	72.1	1.60	6.9	419	5.56
			av	39.3	30.7	26.3	29.9	28.0	103	1.75	7.5	513	13.7
			mn	15.6	15.1	12.1	16.1	15.1	28.2	0.91	3.5	179	0.24
			mx	52.4	40.9	42.1	39.0	36.4	419	2.54	28.0	755	39.2

Notes. Designations*:* FN – field number; CP – control point; ST – sample type; MMS – Mountain Meadow Soddy Peat; MMB – Mountain Meadow Bog; MFM – Mountain Forest Meadow.

Table 3. Radium equivalent activity (Ra_{eq}, Bq/kg), dose rate (D, nGy/h) and annual effective dose (AEDE, mSv/y), ratios of radionuclide activities, their average (*av*), minimum (*mn*) and maximum (*mx*) values in soil samples

#	FN	Ra_{eq}, Bq/kg	D, nGr/h	AEDE, mSv/y	H_{ex}	H_{in}	U-238/ U-235	U-238/ Th-232	Ra-226 /U-238	Pb-210/ Ra-226
1	431-S	125	59.0	0.072	0.35	0.44	15.3	0.80	0.87	0.92
2	432-S	111	54.1	0.066	0.31	0.40	23.3	1.13	0.83	1.41
3	433-S	141	67.3	0.083	0.39	0.50	15.9	0.91	1.04	0.78
4	437-S	123	59.6	0.073	0.34	0.43	17.8	0.81	0.82	3.77
5	439-S	149	71.7	0.088	0.41	0.51	23.7	0.67	1.22	10.11
6	435-S	116	56.1	0.069	0.32	0.39	14.2	0.71	0.66	4.86
7	393-S	105	50.9	0.062	0.29	0.36	13.6	0.78	0.85	6.80
8	394-S	120	57.6	0.071	0.33	0.41	19.3	0.68	-	-
9	395-S	75.8	37.0	0.045	0.21	0.27	20.5	0.92	0.65	15.61
10	396-S	158	77.3	0.095	0.44	0.53	18.4	0.67	0.81	3.09
11	421-S	128	61.8	0.076	0.36	0.44	19.4	0.77	-	-
12	422-S	124	59.5	0.073	0.34	0.43	15.6	0.83	0.76	-
13	423-S	127	61.6	0.076	0.35	0.44	17.5	0.76	0.75	4.47
14	424-S	117	56.8	0.070	0.33	0.40	19.2	0.79	1.05	3.02
15	425-S	164	79.1	0.097	0.45	0.57	17.8	0.79	0.85	2.98
16	426-S	102	49.1	0.060	0.28	0.36	20.1	0.86	0.88	3.22
17	427-S	158	76.8	0.094	0.44	0.53	15.7	0.62	0.84	3.63
18	428-S	128	62.3	0.076	0.36	0.44	15.2	0.72	0.69	6.71
19	429-S	139	67.6	0.083	0.39	0.48	18.0	0.75	0.80	1.66
20	430-S	138	66.6	0.082	0.38	0.47	17.1	0.71	0.87	6.32
21	434-S	125	59.7	0.073	0.35	0.44	19.5	0.86	0.96	1.73
22	436-S	50.0	23.9	0.029	0.14	0.18	16.7	0.97	0.80	2.65
23	438-S	102	49.1	0.060	0.28	0.35	16.4	0.80	0.71	3.92
	av	123	59.3	0.073	0.34	0.42	17.8	0.80	0.84	4.38
	mn	50.0	23.9	0.029	0.14	0.18	13.6	0.62	0.65	0.78
	mx	164	79.1	0.097	0.47	0.58	23.7	1.13	1.22	15.61

All radionuclides identified in the work, with the exception of Cs-137, are of natural origin. They were also observed in the soil in some regions of Western Georgia [10].

The content and activity concentrations of radionuclides of natural origin

identified in the samples generally correspond to those commonly observed [11] for various soils.

The observed features of the activity ratios, in particular, the predominance of increased values of the U-238/Th-232 ratio compared to the average, may be due to the different nature of the geochemical processes of U and Th under the same external conditions. For example, in the works [11, 12], it is noted that Th isotopes in natural media occur only in a tetravalent form; compounds are practically insoluble in waters and are mechanically transported in the form of stable minerals, while U isotopes occur in both 4- and 6-valence forms - in 4-valence form, their chemical properties are close to Th, and in the 6-valence form they are characterized by high chemical activity and migrate over long distances in the form of solutions with waters. The region under study is characterized by a complex hydrogeological structure. During the circulation of groundwater, it is possible to dissolve the uranium of the underlying rocks and its removal to the above-located soil formations, which may cause some enrichment of their by U-238. On the other hand, the reverse migration of Th-232 from the soil to the underlying rocks can cause, accordingly, its depletion. The action of these processes, depending on external factors, can cause the observed deviations of the U-238/Th-232 ratio both down and up from the average value.

Similar processes can cause deviations from equilibrium values the Ra-226/U-238 ratio too. As is known, the isotope Ra is easily leached and washed away by waters: in natural formations, Ra-226 often accumulates in amounts exceeding equilibrium with uranium [11, 12]. The region under study is characterized by a complex hydrogeological structure and the effect of this and other geochemical factors can lead to noticeable variations in the activity of these radionuclides, in particular, causing their observed deviations to a greater extent from equilibrium values.

Of particular interest is the imbalance observed in the work between Ra-226 and Pb-210. Theoretically, Ra-226 and Pb-210 should be in constant equilibrium, but due to the diffusive behavior of the daughter inert gas Rn-222, an imbalance may be observed in natural materials caused by the migration of radon from the lower layers of the soil to the upper (and further into the atmosphere). When Rn-222 enters the air, its daughter products (including Pb-210) settle on the surface of aerosols and dust particles. These daughter isotopes reach the soil surface in the form of wet and dry precipitation and accumulate in the surface layers of the soil. As a result of this process, the concentration of Pb-210 in the surface layer of the soil is higher than expected at equilibrium with Ra-226. The part of the Pb-210 content that is in equilibrium with the activity of Ra-226 is called “supported Pb-210”, and the other part associated with radon migration is called “unsupported Pb-210” (in other words– ”allochthonous") [13, 14]. At the same time, the radioactive equilibrium in the soils is disturbed towards an increase in the activity of Pb-210, i.e. the ratio Pb-210/Ra-226>1

is realized. The activity ratio Pb-210/Ra-226 in soils is an integral characteristic of the existence of a constant or pulsed radon updraft in the system for a long time. To a certain extent, the measure of the amount of excess Pb-210 may be the difference between the measured value of the activity concentration of Pb-210 and the concentration of its parent Ra-226 (Bi-214). As can be seen from the results, the maximum value of this value reaches 377.5 Bq/kg. This value is quite large and indicates the porous texture of the underlying rock layers, and possibly the presence of tectonic disturbances (cracks, cavities, etc.) [15], which can be expected due to the complex tectonic structure in the studied region.

The analysis of the activity ratio U-238/U-235, which in nature should be 21.7, makes it possible to identify cases of soil contamination with enriched or depleted uranium. A clear shift in this ratio undoubtedly indicates the presence of a technogenic impact. The ratio values obtained in this work indicate the absence of any contamination of the soil by technogenic uranium.

The distribution of the natural radionuclide K-40 is mostly close to the values observed in [11].

Radionuclide Be-7 is observed in almost all samples, the concentration of which varies in the range 3.5 – 28.0 Bq/kg. Like other cosmogenic radionuclides, radionuclide Be-7 is formed in the upper layers of the atmosphere when the nuclei of air atoms are split by cosmic radiation, and as a result of atmospheric exchange processes it is transferred to the near-surface layers of air, and then falls to the surface of the Earth with atmospheric precipitation. Due to the insignificant half-life (54 days), the radionuclide Be-7 manifests itself only in the near-surface layers of the soil (up to a depth of about 20 cm), and it makes an insignificant contribution to the increase in the radiation background of the Earth [16]. Nevertheless, beryllium-7 studies provide information on the intensity of various natural processes, for example, to quickly assess the intensity of short-term processes of erosion and sedimentation of soils in the area [17].

Of particular interest are the data for the technogenic radionuclide Cs-137. As can be seen from the results, it was observed in all samples, and the activity concentration values are in the range of 0.24 – 39.2 Bq/kg with an average value of 13.7 Bq/kg. Its presence is usually associated with radioactive contamination of the area by global fallout from nuclear weapons testing products in the period from the late 50s to the mid-60s of the last century, as well as with the 1986 accident of the Chernobyl nuclear power plant, the consequences of which on the territory of Georgia are more pronounced in its western part, in particular on the Black Sea coast. According to a number of data, in particular, according to systematic observations for the lowland regions of Eastern Georgia [18], the values of Cs-137 activity are currently mainly in the range of 1-10 Bq/kg. With a certain degree of conditionality, this level can be considered a background value for the entire territory of Georgia. The values obtained in this work are several

times higher than these values, which may be due to the fact that Cs-137 precipitation on the mountain slopes of the Caucasian slope occurred either with greater intensity than later on lower-lying flat territories, or simultaneously with precipitation, it was washed away from mountain slopes and accumulated in intermountain lowlands, where the samples were taken.

As can be seen from Table 3, the values of the indices (H_{ex}, H_{in}) are below unity – this indicates that these soils do not pose a danger to the population in this region.

Figure 11 shows the correlations of the activity of radionuclides Th-232, U-238 and K-40. As can be seen from the Figure, there is a weaker correlation between the U-238 and K-40 activities (correlation coefficient R^2=0.45) compared with the other two dependencies (R^2=0.67 and R^2=0.77). This is due to various geochemical processes occurring in the soil (migration, erosion, etc., the nature and intensity of which largely depend on the physico-chemical properties of the soil), which require additional research and detailed analysis.

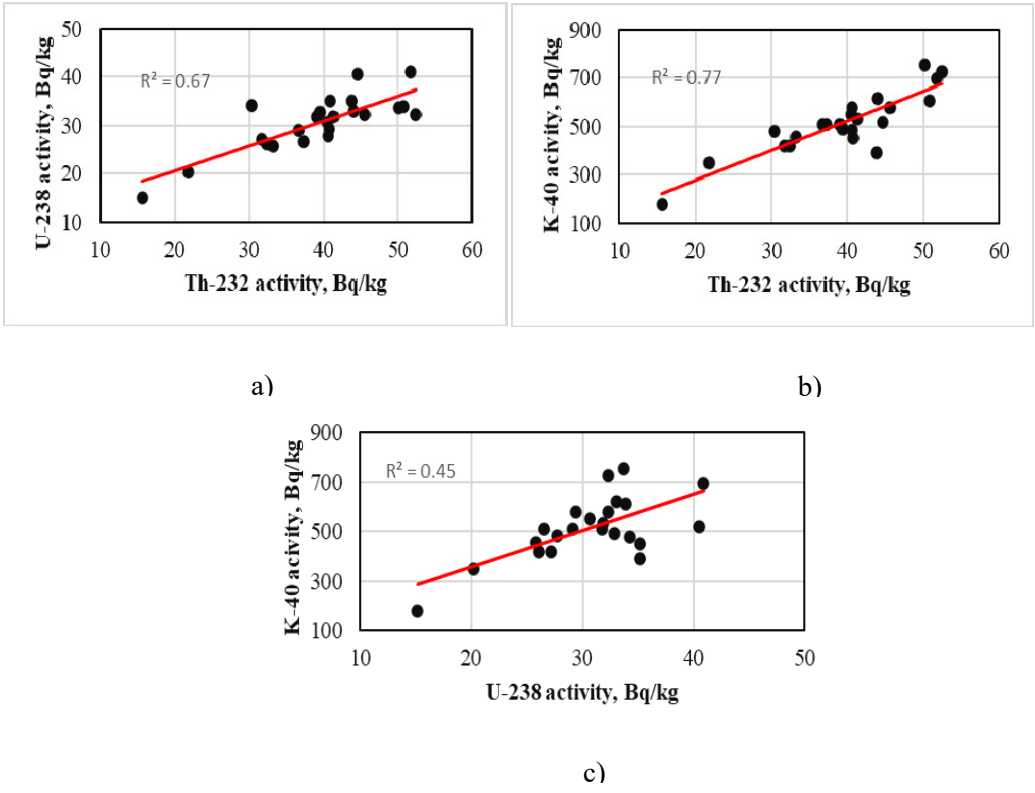
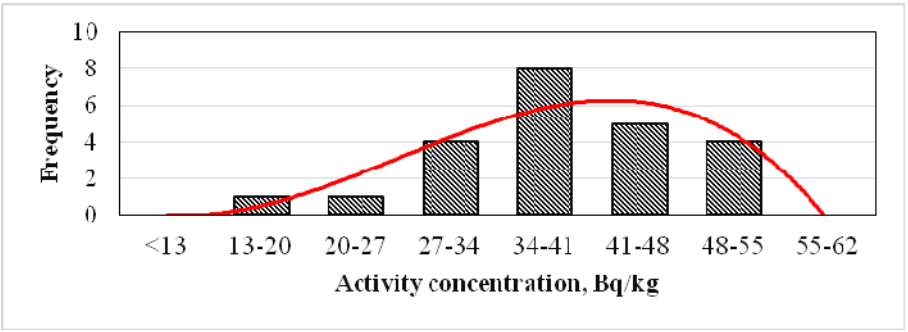
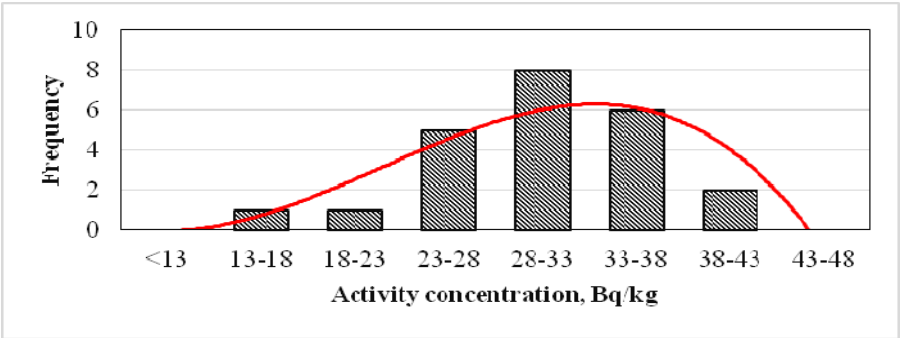


Figure 11. Correlations between the activities of Th-232 and U-238 (a), Th-232 and K-40 (b), U-238 and K-40 (c).

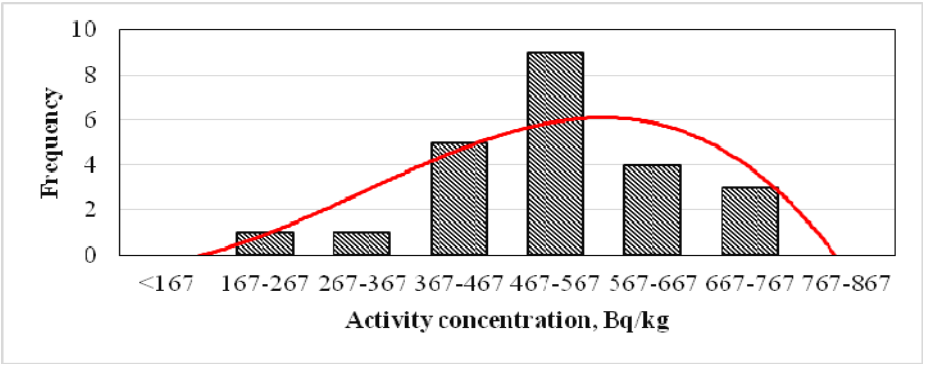
Figure 12 shows the frequency distributions of the activity concentration of radionuclides Th-232, U-238 and K-40.



a)



b)



c)

Figure 12. The frequency distribution of the activity concentration of Th-232 (a), U-238 (b) and K-40 (c)

Table 4 shows some statistical data for these radionuclides, in particular, minimum, maximum, arithmetic mean and geometric mean, median values, standard deviations, Skewness, Kurtosis.

Table 4. Statistical parameters of the distribution of the activity concentration of Th-232, U-238 and K-40

Parameter	Th-232	U-238	K-40
Arithmetic Mean	39.3	30.7	513
min	15.6	15.1	179
max	52.4	40.9	755
Standard Deviation	9.0	5.8	126
Median	40.6	31.8	511
Skewness	-0.87	-0.76	-0.34
Kurtosis	1.12	1.61	1.37

The values of Skewness and Kurtosis from the Table 4 show that the distribution of radionuclide activity deviates to a greater or lesser extent from the normal distribution. The Skewness parameter characterizes the asymmetry of the distribution curve, and its negative values for all radionuclides in this study mean that the distribution is skewed to the left. The Kurtosis coefficient characterizes the measure of peak acuity, and its positive values indicate that the distributions are higher and narrower than normal.

Table 5 shows some literature data on the results of studies conducted in other regions of the world. As can be seen from the Table, the values obtained in this work correspond to values obtained in other regions, as well as global averages. It should also be noted that the value of radium equivalent activity, which varies in the range of 50-164 Bq/kg, is noticeably lower than the recommended value of 370 Bq/kg, and the annual effective dose, which varies in the range of 0.029-0.097 mSv/y, is below the limiting value of 1 mSv/y [19, 20, 21].

Table 5. Activity concentration (A, Bq/kg) of radionuclides in soil and some other parameters in different regions of the world

Country	A, Bq/kg			Ra_{eq}, Bq/kg	D, nGr/h	AEDE, mSv/y	H_{ex}	H_{in}	Ref.
	Th-232	U-238	K-40						
India	53.1 16.7-98.7	26.2 7.7-111.6	635 152-1424	151 53.4-345	117 61.4-202	0.091 0.032-0.203	0.34 0.14-0.47	0.42 0.18-0.58	[22]
Ethiopia	89.2 73.4-120	61.0 46.2-88.5	238 165-397	193 102-290	91.6 72.7-129	0.66 0.53-0.94	0.55 0.44-0.78	0.72 0.56-1.02	[23]
Turkey	34.9 29.9-41.6	50.1 43.8-62.6	200 133-346	122 109-143	60.3 52.2-76.7	0.067 0.060-0.078	0.37 0.29-0.39		[24]
Pakistan	124 4.0-194	69.5 42.6-106	453 49.9-646	281 118-422	101 50.3-149	0.15 0.060-0.24	0.76 0.32-1.14	0.95 0.43-1.43	[25]
Georgia Kvemo Kartli	53.18 39.6-64.9	38.57 25.8-48.8	880 691-1008	182 138-213	89.51 68.3-103.7	0.55 0.42-0.64	0.49 0.37-0.57		[26]
Serbia	53.7 22-64	52 24-72	553 238-730						[27]

Croatia	42.3 37.8-45.8	66.2 50.7-82.4	542 473-621	147 127-156			0.443 .342-0.698		[28]
Brazil	81 5.4-511	34 3.5-100	216 12-1042		67 5-217	0.45 0.0201.43			[29]
Romania	35.5 31.7-41.6	38.1 28.0-47.0	505 435-563	126 117-149	92 87-103	0.074 0.068-0.087	0.34 0.31-0.40		[30]
Ghana	14.6 6.5-29.0	112 75-156	141 84-224	145 133-155	66.9 61.7-71.1	0.09 0.08-0.09			[31]
Montenegro	45.8 18.2-107	41.1 11-216	500 245-753	142 56.8-403	67.5 27.8-185	0.083 0.005-0.227	0.39 0.16-1.10	0.50 0.22-1.42	[32]
Georgia Kazbegi region	39.3 15.6-52.4	30.7 15.1-40.9	513 179-755	123 50-164	59 24-79	0.073 0.029-0.097	0.34 0.14-0.47	0.42 0.18-0.58	Pres. study
Worldwide	45	33	412		58				

Based on the results obtained, it can be concluded that the soil structures in the studied region are characterized by a low degree of radioactivity and do not pose any danger to the population living here.

2.1.2. Rock radioactivity

Table 6 and Table 7 show the results of measuring the activity concentration (A, Bq/kg) of the main radionuclides for the studied samples, radium equivalent activity (Ra_{eq}, Bq/kg), activity ratios, their average (av), minimum (mn) and maximum (mx) values, as well as other data.

Table 6. Activity concentration (A, Bq/kg) of radionuclides of the families Th-232, U-238 (Th-234), U-235, Ra-226, Pb-214, Bi-214, Pb-210), radionuclides Be-7, K-40 and Cs-137, as well as their average (av), minimum (mn) and maximum (mx) values in rocks of various types

#	FN	CP	ST	A, Bq/kg									
				Th-232	U-238	Ra-226	Pb-214	Bi-214	Pb-210	U-235	Be-7	K-40	Cs-137
				Magmatic									
1	398-R	Kz-5	An	31.3	26.8	20.5	25.9	24.3	<M	2.01	-	450	<M
2	400-R	Kz-64	An	41.0	34.5	35.0	32.5	29.6	34.2	2.15	-	610	<M
3	401-R	Kz-4	Dt	45.0	31.8	31.2	31.7	29.5	-	1.51	-	788	<M
4	402-R	Kz-39	An	38.2	29.3	21.7	30.3	28.3	<M	1.98	-	530	-
5	405-R	Kz-59	An	40.0	30.0	21.8	30.7	28.3	28.9	2.17	<M	522	0.54
6	411-R	Kz-54	Dc	37.6	25.8	18.5	26.7	25.7	<M	1.60	4.70	534	-
7	417-R	Kz-37	An	37.5	33.5	35.4	29.6	27.7	<M	2.30	5.58	526	<M
8	418-R	Kz-33	An-Bs	39.5	32.0	29.1	32.0	29.4	41.5	2.40	3.00	593	0.82

9	420-R	Kz-36	An	39.9	33.6	31.7	31.1	29.2	32.5	2.27	6.26	588	<M
			av	38.9	30.8	27.2	30.1	28.0	34.3	2.04	4.88	571	0.68
			mn	31.3	25.8	18.5	25.9	24.3	28.9	1.51	3.00	450	0.54
			mx	45.0	34.5	35.4	32.5	29.6	41.5	2.40	6.26	788	0.82
							Sedimentary						
10	403-R	Kz-42	Tf	42.5	31.5	25.5	33.6	31.2	24.0	2.23	<M	573	<M
11	406-R	Kz-50	Ss	42.4	31.1	27.8	30.3	28.2	30.9	1.91	4.17	632	0.49
12	407-R	Kz-75	Tf	28.1	21.6	24.7	21.1	19.5	24.4	1.21	4.23	441	1.46
13	408-R	Kz-76	Tf	31.7	24.4	20.1	25.5	23.3	20.4	1.49	<M	414	-
14	413-R	Kz-31	Al	57.9	34.5	34.1	33.4	31.4	34.4	2.20	6.63	911	<M
15	414-R	Kz-20	St	41.9	31.7	31.2	30.3	28.7	40.6	2.04	6.22	579	2.69
16	415-R	Kz-10	St	55.0	38.5	34.4	37.4	34.8	50.1	2.15	-	1069	<M
17	416-R	Kz-1	St	19.2	16.5	11.8	17.4	16.1	32.6	1.03	<M	204	-
			av	39.8	28.7	26.2	28.6	26.7	32.2	1.78	5.31	603	1.54
			mn	19.2	16.5	11.8	17.4	16.1	20.4	1.03	4.17	204	0.49
			mx	57.9	38.5	34.4	37.4	34.8	50.1	2.23	6.63	1069	2.69
							Metamorphic						
18	397-R	Kz-55	Cl-Sl	51.7	34.3	-	31.9	29.3	34.9	1.16	<M	844	1.03
19	399-R	Kz-21	Cl-Sl	43.5	36.5	33.2	33.8	31.4	29.1	1.83	1.82	605	<M
20	404-R	Kz-61	Cl-Sl	55.5	32.3	23.3	32.2	30.1	<M	1.96	3.48	910	0.18
21	409-R	Kz-28	Sl	52.4	35.9	39.6	33.1	31.0	21.1	2.12	10.7	703	0.40
22	410-R	Kz-69	Cl-Sl	50.7	35.0	26.7	34.1	31.8	39.0	2.04	<M	711	<M
23	412-R	Kz-66	Cl-Sl	52.0	34.7	34.7	32.5	30.6	-	2.10	7.13	800	0.86
			av	51.0	34.8	31.5	32.9	30.7	31.0	1.87	5.79	762	0.62
			mn	43.5	32.3	23.3	31.9	29.3	21.1	1.16	1.82	605	0.18
			mx	55.5	36.5	39.6	34.1	31.8	39.0	2.12	10.7	910	1.03

Nores. Rock types: An - Andesite; Dc - Dacite; Dt - Diorite An-Bs - Andesite-basalt; Tf – Tuff; Ss - Sandstone; Al - Aleuropelite St – siltstone; Cl-Sl - Clay-slate; Sl – Slate.

Table 7. Radium equivalent activity (Ra_{eq}, Bq/kg), activity ratios U-238/U-235; U-238/U-235, Ra-226/U-238 and Pb-210/Ra-226, dose rate (D, nGy/h) and annual effective dose (AEDE, mSv/y) as well as their average (av), minimum (mn) and maximum (mx) values in rocks of various types

#	FN	CP	ST	Ra_{eq}, Bq/kg	D, nGr/h	AEDE, mSv/y	H_{ex}	H_{in}	U-238/ U-235	U-238/ Th-232	Ra-226/ U-238	Pb-210/ Ra-226
							Magmatic					
1	398-R	Kz-5	An	103	50.0	0.061	0.29	0.36	21.2	0.86	0.77	-
2	400-R	Kz-64	An	136	66.1	0.081	0.38	0.47	17.4	0.84	1.01	0.98
3	401-R	Kz-4	Dt	151	74.7	0.092	0.42	0.51	22.7	0.71	0.98	-
4	402-R	Kz-39	An	121	58.8	0.072	0.34	0.42	21.6	0.77	0.74	-
5	405-R	Kz-59	An	124	59.8	0.073	0.34	0.43	14.1	0.75	0.73	1.32
6	411-R	Kz-54	Dc	117	56.9	0.070	0.33	0.40	18.7	0.68	0.72	-
7	417-R	Kz-37	An	124	60.1	0.074	0.34	0.44	28.5	0.89	1.06	-
8	418-R	Kz-33	An-Bs	130	63.3	0.078	0.36	0.45	15.1	0.81	0.91	1.42
9	420-R	Kz-36	An	132	64.2	0.079	0.37	0.46	23.1	0.84	0.94	1.02
			av	*126*	61.5	0.075	0.35	0.44	*20.3*	*0.80*	*0.87*	*1.19*

			mn	*103*	50.0	0.061	0.29	0.36	*14.1*	*0.68*	*0.72*	*0.98*
			mx	*151*	74.7	0.092	0.42	0.51	*28.5*	*0.89*	*1.06*	*1.42*
						Sedimentary						
10	403-R	Kz-42	Tf	132	64.1	0.079	0.37	0.45	20.9	0.74	0.81	0.94
11	406-R	Kz-50	Ss	136	66.3	0.081	0.38	0.46	20.8	0.73	0.89	1.11
12	407-R	Kz-75	Tf	92.6	45.3	0.056	0.26	0.32	17.6	0.77	1.14	0.99
13	408-R	Kz-76	Tf	99	47.6	0.058	0.27	0.34	17.5	0.77	0.82	1.02
14	413-R	Kz-31	Al	181	88.9	0.109	0.51	0.60	18.1	0.60	0.99	1.01
15	414-R	Kz-20	St	132	64.0	0.079	0.37	0.45	18.8	0.76	0.99	1.30
16	415-R	Kz-10	St	192	95.6	0.117	0.54	0.64	23.8	0.70	0.89	1.46
17	416-R	Kz-1	St	58.2	27.7	0.034	0.16	0.21	14.8	0.86	0.72	2.77
			av	*128*	62.5	0.077	0.36	0.43	*19.0*	*0.74*	*0.91*	*1.32*
			mn	*58.2*	27.7	0.034	0.16	0.21	*14.8*	*0.60*	*0.72*	*0.94*
			mx	*192*	95.6	0.117	0.54	0.64	*23.8*	*0.86*	*1.14*	*2.77*
						Metamorphic						
18	397-R	Kz-55	Cl-Sl	167	82.2	0.101	0.47	0.56	36.1	0.66	-	-
19	399-R	Kz-21	Cl-Sl	141	68.4	0.084	0.39	0.49	23.6	0.84	0.91	0.88
20	404-R	Kz-61	Cl-Sl	175	86.4	0.106	0.49	0.58	27.6	0.58	0.72	-
21	409-R	Kz-28	Sl	160	77.5	0.095	0.45	0.54	18.4	0.69	1.10	0.53
22	410-R	Kz-69	Cl-Sl	157	76.4	0.094	0.44	0.53	17.7	0.69	0.76	1.46
23	412-R	Kz-66	Cl-Sl	165	80.8	0.099	0.46	0.55	20.3	0.67	1.00	-
			av	*161*	78.6	0.096	0.45	0.54	*23.9*	*0.69*	*0.90*	*0.96*
			mn	*141*	68.4	0.084	0.39	0.49	*17.7*	*0.58*	*0.72*	*0.53*
			mx	*175*	86.4	0.106	0.49	0.58	*36.1*	*0.84*	*1.10*	*1.46*

The activity of radionuclides of the families varies significantly in different samples (Table 6), in particular, Th-232 – in the range of 19.2-57.9 Bq/kg (on average 42.4 Bq/kg), U-238 – 16.5-38.5 Bq/kg (31.1 Bq/kg), Ra-226 - 11.8-39.6 Bq/kg (27.8 Bq/kg), U-235 - 1.03-2.40 Bq/kg (1.91 Bq/kg). K-40 activity varies in the range of 204-1069 Bq/kg (632 Bq/kg). Be-7 was recorded in 12 samples in the range from 1.82 to 10.7 Bq/kg (in some samples - in trace amounts) Technogenic radionuclide Cs-137 was recorded in 9 samples in small quantities (0.18-2.69 Bq/kg), and in some samples it was recorded in trace amounts. The activity ratios of U-238/U-235 vary in the range from 14.1 to 36.1 with an average value of 20.8, and generally correspond to the value of 21.7 (accepted for natural objects). The ratio U-238/Th-232 in most samples (14 out of 23) is within ± 10% of the average value of 0.81 (for closed systems), and in the remaining samples deviate from the average value in a smaller direction (from 0.58 to 0.71). The Ra-226/U-238 ratios for 10 samples are within ± 10% of the equilibrium value, for 11 samples less than the equilibrium value (0.72-0.89), and in one sample more than the equilibrium value (1.14). The Pb-210/Ra-226 ratio for 8 out of 15 samples was within ± 20%[3] of the equilibrium value, in some samples they differed from the equilibrium value by more than ±

[3] The range of limits has been expanded, since the error of Pb-210 reached 20%.

20% - in 6 samples more, and in 1 sample less (Note: the ratios of radionuclide activity were not determined in all samples, so as in a number of samples, the activity of the corresponding radionuclides was less than MDA or was not recorded). The values of radium equivalent activity varied in the range of 58-192 Bq/kg (average value of 136 Bq/kg), while the lowest activity was observed for sedimentary rock samples with an average value of 58.2 Bq/kg, and for samples of magmatic and metamorphic rocks, the average Ra_{eq} values were 103 and 141 Bq/kg, respectively. Similarly, lower absorbed dose rates were observed for sedimentary rock samples (27.7 nGy/h) compared with samples of magmatic (50.0 nGy/h) and metamorphic (68.4 nGy/h) rocks, and, accordingly, the values of the annual effective dose varied from the lowest values for sedimentary rocks (with an average value of 0.034 mSv/y) to high values for magmatic (0.061 mSv/y) and metamorphic (0.084 mSv/y) rocks. It should be noted that the main number of samples (87.0%) in terms of activity in radium equivalent belongs to groups with medium radioactivity, and a small number of samples (13.0%) belongs to the group with low radioactivity (Table 7).

As noted above, rock samples were taken in a geological area characterized by a sufficiently complex geotectonic structure. The types of samples collected corresponded to all three main groups of rocks – magmatic, sedimentary and metamorphic. Each of these groups has a specific mineralogical and chemical composition, as well as a mechanism of rock formation, which is mainly associated with a large range of radioactivity concentrations occurring for almost all identified radionuclides, as well as the activity ratios of some radionuclides.

As for the studied soil samples, the values of the U-238/U-235 ratio obtained for all samples correspond to the natural value within the margin of error, which, in addition to the methodological aspect, allows us to conclude that there is no pollution by anthropogenic U-235. The ratios of U-238/Th-232 and Ra-226/U-238, which are close to the average and equilibrium values for magmatic samples, allow us to conclude that these primary rocks apparently represent closed systems. To a certain extent, this is confirmed by a slight deviation of the Pb-210/Ra-226 ratio from the equilibrium value (which can be explained by the compacted texture of these rocks).

However, the features of the activity ratio observed in sedimentary and metamorphic samples (which are secondary rocks), in particular, deviations from the average value of the U-238/Th-232 ratio and the equilibrium value of Ra-226/U-238 indicate that these systems were not closed, and in the past, there were various geochemical processes.

For example, in works [11, 12] it is noted that Th isotopes, which in natural environments occur only in a tetravalent form, form compounds practically insoluble in water and are transferred mechanically in the form of stable minerals, while U isotopes occur in both 4- and 6-valence forms - in the 4-valence form, they are close to Th in chemical properties, and in the 6-valence form they are characterized by high chemical activity, and migrate over long distances in the form of solutions with waters. These processes can lead to a decrease in the U-238/Th-232 ratio relative to the average value, especially in metamorphic rocks, where an increased porous structure could contribute to their greater intensification (which was observed, for example, in samples 397-R, 404-R, 409-R, 410-R, and 412-R).

These same factors, as well as the influence of hypergenesis (weathering), can lead to an imbalance in the radioactive series of the family, in particular, between U and Ra. Here, in addition to the above reasons, the influence of differences in the chemical properties of the elements is significant. In particular, the isotope Ra is easily leached and washed away by waters: in natural formations, Ra-226 often accumulates in quantities exceeding equilibrium with uranium. In the studied samples, deviations from the equilibrium values are relatively small, from which it can be concluded that the above factors played an insignificant role in this region.

The more noticeable deviations of the U-238/Th-232 activity ratios from the average values observed in the work for sedimentary and metamorphic rocks are apparently determined to a greater extent by the processes of hypergenesis. As is known, the Cretaceous period (when most sedimentary rocks were formed) was characterized by the dominance of land on Earth, the climate was hot and dry, deposits of chalk, carbonates, clay shales and others were formed. Mountain systems were formed, and before that, inland seas and vast swamps. All this contributed to the intensification of the process of hypergenesis, intensive leaching of radioactive elements in the process of rock formation or metamorphism. As a result, there was a noticeable decrease in the content of radioactive elements in these rocks. After the Cretaceous period, the climate changed, the temperature dropped, and this factor contributed to a change in the conditions of hypergenesis, which could contribute to an increase in the content of radionuclides during rock formation (which we observe for samples of the Neogene and Quaternary periods).

There is no significant deviation from the equilibrium value in the Pb-210/Ra-226 ratio, which is also noted in [12] for rocks. It can be assumed that the absence of superequilibrium (allochthonous) Pb-210 in rocks (compared to soils, where its noticeable presence is often recorded) is due to their compacted

structure, as a result of which, as noted above, radionuclides are in a “sealed” state in them, and radon migration does not take place in them. The slight excess observed in several samples may be associated with the deposition of Pb-210 from atmospheric air.

The insignificant concentrations of the natural radionuclide Be-7 observed in some samples appear in the samples as a result of precipitation, and in some cases can be identified in gamma spectra.

Technogenic radionuclide Cs-137 also gets onto samples as a result of atmospheric precipitation. Usually, the presence of Cs-137 in natural objects (for example, in soil) is associated, as mentioned above, with the Chernobyl disaster. Over the past period, its number has decreased as a result of both disintegration and migration. In the conducted studies, it was observed in several samples in insignificant concentrations (compared with soils where its concentration is noticeably higher), which is apparently due to the intensive process of leaching from the surface of the samples.

The obtained activity values in radium equivalent are noticeably lower than the recommended value of 370 Bq/kg [20, 21].

2.2. Soil gas radon

The results of measurements of the concentration of radon activity in the soil air are shown in Table 8.

As can be seen from Table 8, the average radon concentrations vary from 73 to 2080 Bq/m^3. At the same time, for six of the eight control points, the average radon concentrations do not exceed the level of 1000 Bq/m^3, and in the two remaining points they are in the range of 1900 – 2100 Bq/m^3.

Table 8. Average concentrations of radon activity (A_{Rn}, Bq/m^3) in soil air

Control point	A_{Rn}, Bq/m^3	Control point	A_{Rn}, Bq/m^3
Kz-7	73	Kz-25	169
Kz-15	221	Kz-45	180
Kz-18	507	Kz-60	127
Kz-23	2080	Kz-73	1930

It should be noted that radon, which is an odorless, colorless and tasteless gas, is a product of the decay of natural uranium found in rocks and soils.

Therefore, radon is always present in most materials and is released through soil fragments into the surrounding atmosphere and the indoor air of rooms and buildings. The radon content in the soil and in the air of buildings is determined by the geological component of the territory, its inherent rocks, and the content of natural radionuclides in them, the presence of tectonic disturbances and other factors. Radon is extremely unevenly distributed in the bowels of the earth, since it accumulates in tectonic disturbances, where it enters through systems of microcracks from rocks.

The volume activity of radon in soil air can range from several thousand to several hundred thousand Bq/m^3. For example, the arithmetic mean concentration of radon in various soil types in the territory of one of the regions of Brazil varied in the range from 13.6 to 60.6 kBq/m^3 [33]. Similar studies conducted in Turkey showed that the radon concentration in the soil air varied in the range from 17.65 to 66.71 kBq/m^3 [34]. Measurements carried out at 31 control locations in China showed that the concentration of radon activity in soil air varies from 2 to 14 kBq/m^3 [35]. The concentration of soil radon in two studied profiles in Romania varied in the ranges from 1.6 to 19.2 kBq/m^3 and from 1.2 to 30.6 kBq/m^3, respectively [36]. The soil gas radon concentration around the Upper Siwaliks, India, was found to vary from 11.5 to 78.47 kBq/m^3 [37].

In an open area, radon released from the soil is rapidly dispersed in an almost unlimited volume of outdoor air. Therefore, its activity in the atmosphere becomes several orders of magnitude lower than in the soil. For example, when radon activity in the soil ranges from 5,000 to 110,000 Bq/m^3, radon activity in the outdoor air drops to 5-20 Bq/m^3. As a result, the concentration of radon in the atmospheric air quickly drops to a very low level and, as a rule, does not pose a danger. However, indoors, as well as in poorly ventilated areas, the concentration is higher, with the highest concentration levels observed in mines, caves and water treatment plants. In buildings, such as residential buildings, schools, and offices, radon concentration levels can vary greatly. The main factors affecting the concentration of radon inside buildings are both the geological features of the area, for example, the uranium content and permeability of the underlying rocks and soils, and the ways radon enters the building from the ground. Thus, studies of soil radon concentrations play an important role in the study of internal radon and its effects on human health.

The concentrations of soil radon obtained in this work are quite low. As a result, it is obvious that the concentration of radon in the premises in this area does not pose any danger to the local population. Nevertheless, direct measurement of the concentration of internal radon in local residential buildings and other buildings may be of some interest in further research.

2.3. Dosimetry

The results of measurements of the ambient dose equivalent rate of gamma radiation AEDR (H*(10)) are shown in Table 9.

Table 9. Ambient dose equivalent rate AEDR (H*(10)), μSv/h

Control point	AEDR (H*(10)), μSv/h	Control point	AEDR (H*(10)), μSv/h	Control point	AEDR (H*(10)), μSv/h
Kz-2	0.07	Kz-29	0.16	Kz-53	0.10
Kz-8	0.11	Kz-32	0.11	Kz-58	0.10
Kz-11	0.11	Kz-34	0.11	Kz-61	0.14
Kz-13	0.09	Kz-38	0.12	Kz-66	0.14
Kz-16	0.09	Kz-43	0.12	Kz-69	0.09
Kz-19	0.11	Kz-47	0.08	Kz-71	0.08
Kz-24	0.09	Kz-49	0.07	Kz-72	0.09
Kz-26	0.12	Kz-51	0.06		

As can be seen from Table 9, the values of AEDR (H*(10)) varied in the range from 0.06 to 0.16 μSv/h, with the average value being 0.10 μSv/h.

It should be noted that the main sources of natural gamma background are:

- environmental radioactivity from natural radioactive materials in the ground – the average equivalent dose rate on the ground is 0.04 μSv/h;
- secondary cosmic photon radiation – the average dose rate at an altitude of 0 m above sea level in the middle latitudes is 0.032 μSv/h.

Summing these values with the natural background of the used dosimetric equipment (on average 0.2 - 0.3 μSv/h), dose rate values at the level of 0.09 – 0.10 μSv/h are obtained, which generally corresponds to the values obtained in this work.

It should also be noted that Georgian and international standards provide for certain radiation standards, according to which the maximum permissible norm for the general population is 1 mSv/year. At the same time, the standard indicator for the dose rate is from 0.05 to 0.20 μSv/h. If the constant background level exceeds 1.2 μSv/h, it poses a serious threat to human health.

The Earth's gamma background is mainly determined by the specific activity of rocks, which depends on their composition. In particular, granites always contain elevated concentrations of uranium. The basis of the Kazbegi mountain range is made up of sandstones, which are characterized by medium radioactivity, which is determined by the low level of gamma radioactivity of the studied territory.

The analysis of the received dose rate values showed that a relatively lower range of values (0.06 – 0.10 μSv/h) corresponds to measurements carried

out over the soil area, and relatively higher values (0.11 – 0.16 μSv/h) correspond to measurements directly above the rock outlet. In addition, the background radiation depends on how close the rocks come to the surface.

In general, it should be noted that all the dose rates obtained are less than the maximum safe level of irradiation of the human body, which is 0.20 μSv/h (at the same time, the threshold of 0.30 μSv/h is considered a safe level for humans, i.e. irradiation with a dose of 0.30 μSv for an hour).

CONCLUSION

The present study was devoted to the study of the radioecological condition of the territory of the Kazbegi municipality. To solve this problem, a study was conducted of the radionuclide content of various soil and rock samples taken on the territory of the municipality, the activity concentration of radioactive radon gas in the soil air, the level of gamma-background (ambient dose equivalent power).

As a result of the conducted studies, it was found that up to 22 radionuclides are mainly detected in the selected samples of both soil and rocks, in particular: family Th-232 - Ac-228, Th-228, Ra-224, Pb-212, Bi-212, Tl-208 (total 6 radionuclides); family U-238 – Th-234, Pa-234, Th-230, Ra-226, Pb-214, Bi-214, Pb-210 (7 radionuclides in total); family U-235 - U-235, Th-231, Th-227, Ra-223, Rn-219, Pb-211 (total 6 radionuclides); other natural radionuclides Be-7, K-40, technogenic radionuclide Cs-137. For soil samples, the average activity values of radionuclides of the Th-232 and U-238 families are approximately the same level (39.3 Bq/kg and 30.7 Bq/kg, respectively) and significantly exceed the average activity value of radionuclides of the U-235 family (1.75 Bq/kg). The average activity value of the natural radionuclide K-40 was 513 Bq/kg. The cosmogenic radionuclide Be-7 was detected in most samples (the average activity value was 7.5 Bq/kg). The radionuclide Cs-137 was detected in almost all samples (the average activity value is 13.7 Bq/kg). The radium equivalent activity, which varies in the range of 50-164 Bq/kg, is noticeably lower than the recommended value of 370 Bq/kg, and the annual effective dose, which varies in the range of 0.029-0.097 mSv/y, is below the limiting value of 1 mSv/y. Based on the results obtained, it can be concluded that the soil structures in the studied region are characterized by a low degree of radioactivity and do not pose any danger to the population living here.

Similar results were obtained for rock samples: the average values of

radionuclide activity were 42.4 Bq/kg and 31.1 Bq/kg for the Th-232 and U-238 families, which is significantly higher compared to the U-235 family (1.91 Bq/kg); K-40 activity varies in the range of 204-1069 Bq/kg (632 Bq/kg); small amounts of natural radionuclide Be-7 and technogenic radionuclide Cs-137 were recorded in some samples. The main number of samples (87%) in terms of activity in radium equivalent belongs to groups with medium radioactivity, and a small number of samples (13%) belong to the group with low radioactivity. The obtained activity values in radium equivalent are noticeably lower than the recommended value of 370 Bq/kg.

The average concentrations of radon radioactive gas activity in the soil air varied from 73 to 2080 Bq/m^3. The values of the ambient dose equivalent of gamma radiation varied in the range from 0.06 to 0.16 μSv/h, with an average value of 0.10 μSv/h.

The obtained research results are compared with the literature data. It is shown that the values obtained in this work are not characterized by extreme values, are at the level of global averages and below the recommended standards of radiological safety.

Thus, the radioecological situation of the territory of the Kazbegi municipality can be assessed as normal, posing no danger to the resident population and numerous tourists.

Figure 13. The house-museum of the writer A. Kazbegi in Stepantsminda

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