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Distribution of natural radionuclides in the soils and assessment of radiation hazards in the Khrami Late Variscan crystal massif (Georgia)

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Abstract

This study was performed to determine the distributions of radionuclides (^{238}U, ^{232}Th and ^{40}K naturally occurring in Khrami Late Variscan crystal massif and soils overlapping its adjacent territory built by Neogene and Quaternary lava using a gamma-ray spectrometry with an HPGe detector. By identification of artificial radionuclide ^{137}Cs concentration revealed the character of radioactive contamination of the area under investigation. Based on the obtained results, the radiological parameters (outdoor absorbed gamma dose rate, annual effective dose; radium equivalent activity) were estimated to assess radiation hazards caused by use of industrial materials. The difference was established between concentrations of radionuclides having emerged at the expense of Late Variscan crystal substrate and recently erupted lavas. The results were compared with similar studies conducted in different countries and with data and recommendations published by international organizations (UNSCEAR, ICRP).

1. Introduction

As it is known, natural radioactive substances in the soil are constant sources of human irradiation (terrestrial radiation). According to periodic reports published by The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the average part of radiation coming from natural sources equals to 2.4 mSv/y, whereas the share of radiation from artificial sources is 0,8 mSv/y (UNSCEAR, 2000; Dhawal et al., 2013). Thus, 75% of total radiation affecting human health falls on natural radiation sources. Consequently, the great importance of studying the existing natural radiation of radioactive sources and assessment of radiation hazards is quite apparent. The major exposure to radiation caused by soil radiation comes from the upper layer of the soil (Dhawal et al., 2013; Hussain and Hussain, 2011), in which the sources of radioactivity are ^{238}U, ^{232}Th, their decay products and radionuclide ^{40}K. Radiological impact of natural radionuclides on humans is mainly expressed by gamma radiation affecting the body, as well as by radon and the processes caused by inhalation of its decay products (Hussain and Hussain, 2011).

Natural radioactivity of the soil and ionizing gamma radiation coming from soil depends on the concentration of natural radionuclides it contains, while the latter depends on soil forming parent rock and other forming factors (UNSCEAR, 2000; Dhawal et al., 2013; Alaamer, 2008). In general, relatively increased radioactivity are associated with igneous rocks and the decreased — with sedimentary rocks. However, there are some exceptions: for instance, some shales and phosphates show relatively high content of radionuclides. Igneous rocks, namely, sialic rocks (especially granitoids) contain a relatively higher concentration of natural radionuclides than ultramafic and mafic rocks (UNSCEAR, 2000; Dhawal et al., 2013).

In Georgia granitoids are occurred in axial region of Caucasus Main Ridge, as well as crystal massifs of Dzirula, Khrami and Loki. At this stage, Khrami massif as a study area was selected for our research. During the selection, some other important factors, apart from the spread of granitoids, were considered, such as: the existence of populated localities, agricultural and mining (of natural industrial materials) activities etc.

2. Material and methods

2.1. Area under research

The territory selected for this research covers 20 km^2 of Tsalka municipality in Kvemo Kartli region (Fig. 1). According to existing geological data (Geological map, 1995) the most widely spread rocks here are: Late Variscan granitoids building
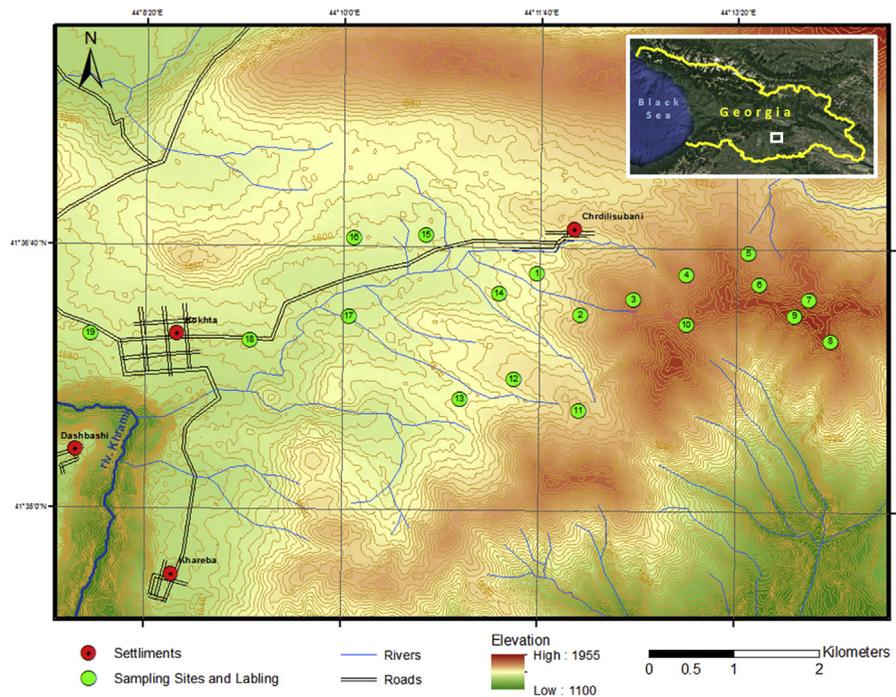
Fig. 1. Study area and sampling sites.

Khrami crystal massif, granodiorites, gneisses, adjacent and partly overlapping continental basaltic lava of Neogene and Quaternary of calc-alkaline series, continental and shallow marine volcanoclastic rocks, and other (Fig. 2). As for soils, the most widely spread ones on the territory under research is black soil (Soil map, 1999).

2.2. Sampling and processing

The sampling scheme was selected according to spread of rocks, allowing the determination of the correlations between research parameters and geological and geographical features of the area.

Totally 19 samples were collected from the territory. All samples were taken in the distance from populated localities and buildings or other infrastructural constructions, in order to exclude the occurrence of endemic soil or any other materials in the samples to the greatest possible extent.

To get a generalized picture of radionuclide distribution and formation of background radiation by means of existing sampling methodology on the research territory, so called "envelope" method was selected (Resolution #35, 2014), according to which, five samples (30−40 meters away from each other) in each sampling site were taken (Fig. 3) and averaged by means of mixing (i.e. totally 95 samples were taken).

Table 1 shows geographical coordinates recorded on the central point of sampling site and shows agricultural purpose of the soils and the soil parent material.
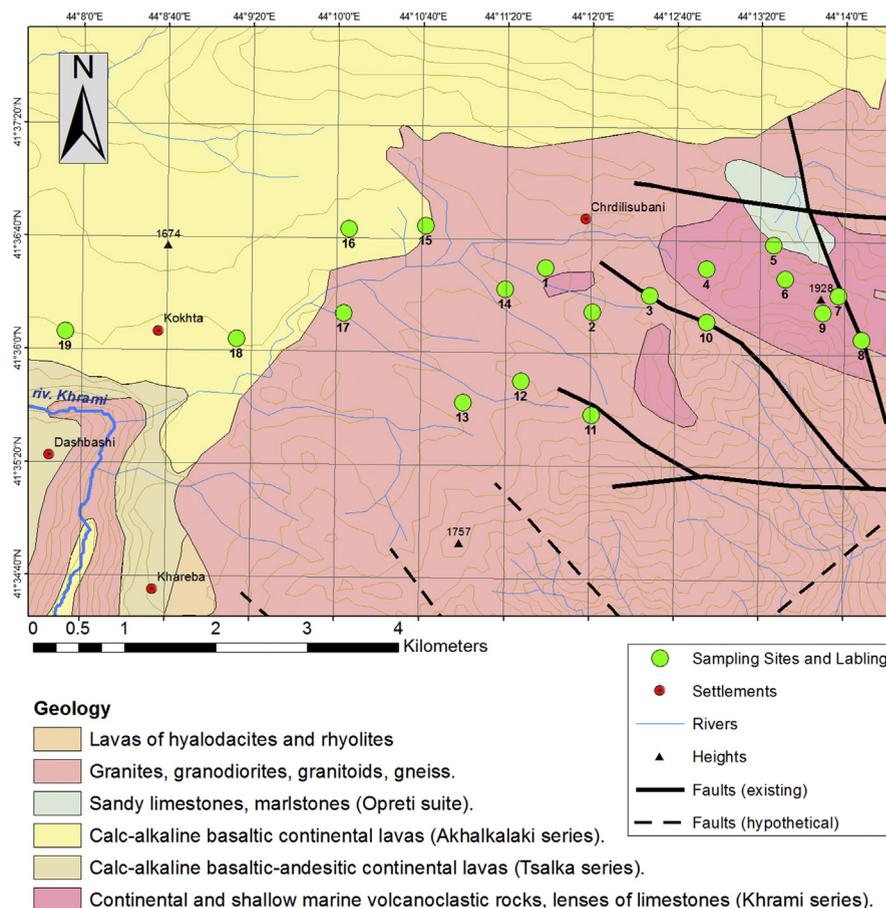
Fig. 2. Geological map of the study area.

The distance between sampling sites was 600−800 meters on average. Sampling took place at the depth of 15−20 cm under the surface of the soil. The primary processing of samples took place on site (removing stones and roots from the soil samples) and as a result 200−250 grams of soil fractions was obtained.

For laboratory measurements the samples were further prepared with well approved methods (Dhawal et al., 2013; Hussain and Hussain, 2011; Alaamer, 2008; Kessaratikoon and Awaekechi, 2008): At first, obtained samples were air dried at room temperature; After this, samples were sifted, first in a sift with 1.5 mm cells and then with 1 mm sells; Finally, samples were placed in hermetically sealed double polyethylene containers and stored for 3 months to reach the equilibrium of ^{214}Pb and ^{214}Bi with ^{222}Rn.

2.3. Laboratory research

A well approved gamma-spectroscopy method was used to determine activity concentrations of radionuclides in soil samples. Measurements was made at the Applied
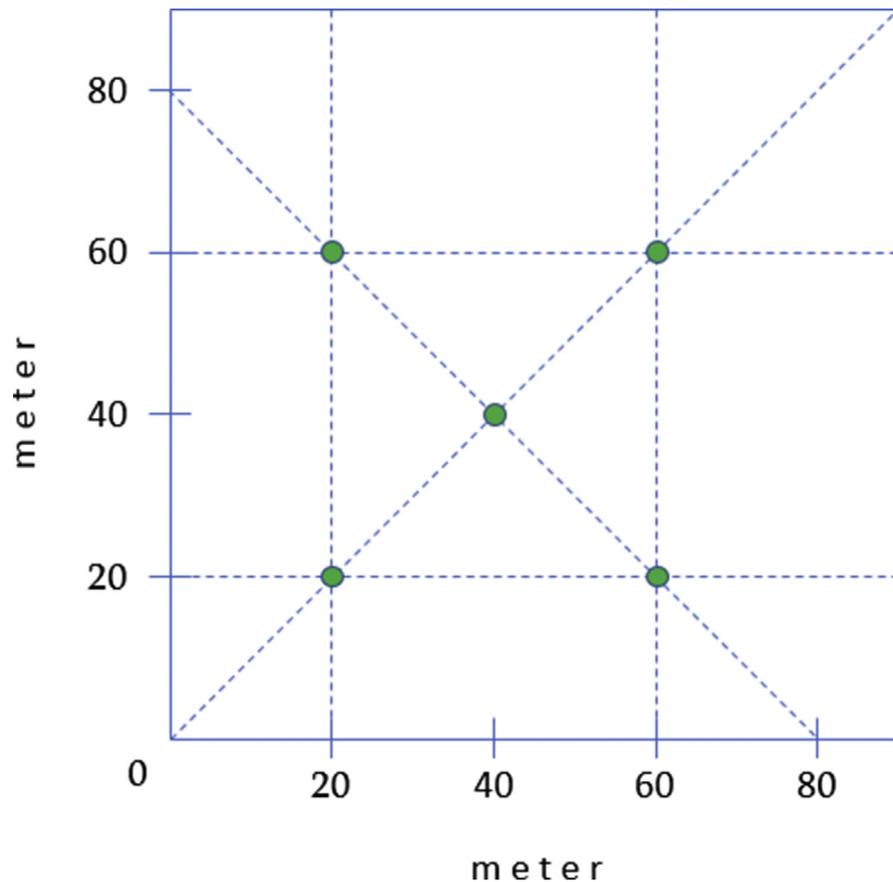
Fig. 3. "Envelope" method of sampling.

Research Centre Laboratory of Radiological Studies at Ivane Javakhishvili Tbilisi State University Elefter Andronikashvili Institute of Physics.

For measurements was used semiconductor (detector), based on high-purity germanium (HPGe) crystal (manufacturer CANBERRA; detector model: GC3018; crystal model: CP-5SL; S/N: 07079313). The spectrometer was calibrated for energy by acquiring a spectrum from radioactive standard sources of known energies like ^{60}Co (1332 keV, 1773 keV) and ^{137}Cs (662 keV). HPGe detector was coupled with a Canberra multichannel analyzer (MCA). The resolution (FWHM) of the spectrometry system was 1.8 keV at 1332 keV gamma-ray line of ^{60}Co. Spectrum of every sample was collected for 25000 seconds (7 h). Spectrum analysis was performed with using of computer gamma analysis software Genie-2000 (model: S501) and calibration software LabBOCS (model: S574) and ISOCS (model: S573).

As mentioned above, before gamma spectrometric analysis soil samples were sealed for 3 months to reach the equilibrium of ^{214}Pb and ^{214}Bi with ^{222}Rn. It was assumed that ^{226}Ra and ^{228}U are in equilibrium.

Table 1. Characteristics of sampling sites.

Site #	GPS Coordinates	Altitude (m)	Agricultural purpose	Lithology
1	41° 36.503′N 44° 11.643′E	1637	Pasture	Granite
2	41° 36.244′N 44° 12.014′E	1681	Pasture	Granite
3	41° 36.344′N 44° 12.465′E	1799	Pasture	Granite
4	41° 36.500′N 44° 12.914′E	1779	Pasture	Granite
5	41° 36.645′N 44° 13.437′E	1771	Pasture	Volcanoclastic
6	41° 36.447′N 44° 13.531′E	1839	Pasture	Volcanoclastic
7	41° 36.350′N 44° 13.953′E	1870	Pasture	Volcanoclastic
8	41° 36.090′N 44° 14.136′E	1873	Pasture	Granite
9	41° 36.248′N 44° 13.828′E	1912	Pasture	Volcanoclastic
10	41° 36.187′N 44° 12.914′E	1813	Pasture	Granite
11	41° 35.636′N 44° 12.011′E	1687	Treated	Granite
12	41° 35.833′N 44° 11.458′E	1655	Treated	Granite
13	41° 35.703′N 44° 11.000′E	1624	Treated	Granite
14	41° 36.375′N 44° 11.329′E	1614	Old treated	Granite
15	41° 36.746′N 44° 10.701′E	1594	Old treated	Basalt/Granite
16	41° 36.724′N 44° 10.091′E	1597	Old treated	Basalt
17	41° 36.225′N 44° 10.056′E	1579	Old treated	Granite
18	41° 36.070′N 44° 9.216′E	1568	Old treated	Basalt
19	41° 36.106′N 44° 7.870′E	1573	Pasture	Basalt

The activity concentration of ^{238}U was determined by measuring the 609.20 keV peak from ^{214}Bi (intensity 48.0%) and 351.96 keV peak from ^{214}Pb (intensity 39.3%). The activity concentration of ^{232}Th was determined by measuring 911.20 keV peak from ^{228}Ac (intensity 25.80%) and 583.19 keV peak from ^{208}Tl (intensity 84.50%). The activity concentrations of ^{40}K and ^{137}Cs was determined using a single peaks of 1461.0 keV (intensity 10.72%) and 661.7 keV (intensity 90.11%) for the ^{40}K and ^{137}Cs respectively.

To measure the activity concentrations of radionuclide i in Bq/kg, for the peak energy E, the following equation was used (Dhawal et al., 2013; Hussain and Hussain, 2011; Alaamer, 2008):

$$A_{Ei} = \frac{C_{Ei}}{C_{eff} \cdot \gamma \cdot m \cdot t} \tag{1}$$

where C_{Ei} is the total count of a peak at energy E, C_{eff} is the detection efficiency at energy E, γ is the percentage of gamma emission probability of the radionuclide i for a transition at energy E, m is the mass in kg of the measured sample and t is the counting time.

3. Results

3.1. Concentrations of radionuclides

As a result of gamma spectrometry analysis for 19 samples activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg was determined and their contents in g/kg was calculated. The results are provided in Table 2, where apart from natural sources it shows ^{137}Cs of one of the most important artificial soil pollutant concentrations.

As it can be seen from Table 2, in our case the mean values of activity concentrations are: 38.57 Bq/kg, 53.18 Bq/kg and 879.76 Bq/kg, for ^{238}U, ^{232}Th and ^{40}K respectively, which exceeds the world mean values (also provided in Table 2) for Uranium 35 Bq/kg by 3.57 Bq/kg, for Thorium 30 Bq/kg by 18.18 Bq/kg, for Potassium 400 Bq/kg by 479.76 Bq/kg (UNSCEAR, 2000; Hussain and Hussain, 2011).

Table 2. Concentrations of radionuclides in soil samples.

Site #	Bq/kg				g/kg			
	^{238}U	^{232}Th	^{40}K	^{137}Cs	^{238}U	^{232}Th	^{40}K	^{137}Cs
1	42.50	44.40	690.60	10.60	0.00345	0.01100	0.00267	$33*10^{-13}$
2	39.40	53.80	745.80	9.60	0.00320	0.01330	0.00289	$30*10^{-13}$
3	38.70	50.70	936.00	4.50	0.00314	0.01250	0.00362	$14*10^{-13}$
4	38.30	51.40	933.00	11.50	0.00311	0.01266	0.00361	$35.9*10^{-13}$
5	39.60	50.00	867.30	5.50	0.00321	0.01232	0.00336	$17.2*10^{-13}$
6	40.67	50.50	933.00	3.75	0.00330	0.01240	0.00361	$11.71*10^{-13}$
7	43.44	56.50	1008.00	12.26	0.00352	0.01392	0.00390	$38.3*10^{-13}$
8	40.45	54.40	944.00	11.30	0.00328	0.01340	0.00365	$35.3*10^{-13}$
9	38.00	60.20	1004.80	33.00	0.00308	0.01483	0.00389	$1.0*10^{-11}$
10	33.00	48.90	956.00	8.50	0.00268	0.01205	0.00370	$27*10^{-13}$
11	41.20	59.90	768.50	10.00	0.00334	0.01475	0.00297	$32*10^{-13}$
12	35.70	52.00	784.20	10.20	0.00290	0.01280	0.00303	$32*10^{-13}$
13	29.30	50.70	778.60	13.00	0.00238	0.01250	0.00301	$41*10^{-13}$
14	36.00	54.50	957.50	10.00	0.00292	0.01340	0.00371	$32*10^{-13}$
15	48.80	63.20	954.50	8.50	0.00396	0.01560	0.00369	$27*10^{-13}$
16	44.30	53.90	837.50	10.70	0.00360	0.01330	0.00324	$34*10^{-13}$
17	42.80	64.90	975.00	8.30	0.00343	0.01600	0.00377	$26*10^{-13}$
18	34.90	51.00	918.40	13.30	0.00283	0.01260	0.00355	$42*10^{-13}$
19	25.80	39.60	722.80	7.90	0.00210	0.00980	0.00280	$25*10^{-13}$
Min.	25.80	39.60	690.60	3.75	0.00210	0.0098	0.00267	$11.71*10^{-13}$
Max.	48.80	64.90	1008.00	33.00	0.00396	0.01600	0.00390	$1.0*10^{-11}$
Mean	38.57	53.18	879.76	10.65	0.00313	0.01310	0.00340	$3.33*10^{-12}$
World's average (UNSCEAR 2000)	35	30	400	-	0.00284	0.00739	0.00155	-

As for ^{137}Cs, as it can be seen from Table 2, activity concentrations of ^{137}Cs fluctuates between 3.75 Bq/kg and 33 Bq/kg with the mean value of 10.53 Bq/kg.

3.2. Absorbed dose rate in air (D)

If the activity concentrations of radionuclides in soil is known assuming that radionuclides are uniformly distributed in the soil, then exposure dose rate in air causing these radionuclides can be found (UNSCEAR, 2000; Dhawal et al., 2013; Hussain and Hussain, 2011). The absorbed dose rate in air is calculated by the following formula (UNSCEAR, 2000):

$$D = 0.462A_U + 0.604A_{Th} + 0.0417A_K \qquad (2)$$

where D denotes the dose rate in the air at 1 m above the ground surface; A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively in the soil sample; 0.462, 0.604 and 0,0417 are dose conversion factors for ^{238}U, ^{232}Th and ^{40}K respectively.

Table 3 shows the results calculated for absorbed dose rate in the air. The mean value of our results is equal to 86.63 nGy/h. That considerably exceeds the world mean value which is 57 nGy/h (Dhawal et al., 2013; Kessaratikoon and Awaekechi, 2008).

3.3. Annual effective dose rate (E)

When calculating the annual effective dose rate exposure to population, the following factors should be taken into account (UNSCEAR, 2000; Hussain and Hussain, 2011): a) Coefficient of transferring from absorbed dose to effective dose (0.7 Sv/Gy) and b) So called "occupation factor", i.e. how long a human stays outdoor and indoor. According to UNSCEAR 2000, these factors are 0.2 and 0.8 (a person spends 20% of time outdoors and 80%-indoors). A summarized effective dose rate is calculated by means of the following formula (Dhawal et al., 2013; Alaamer, 2008):

$$E = T \times Q \times D \times 10^{-6} \qquad (3)$$

where D is the absorbed dose rate in the air; Q is the conversion factor of 0.7 Sv/Gy, which converts the absorbed dose rate in the air to human effective dose received; and T is the time during 1 year, i.e. 8760 hrs.

According to the results given in Table 3, in our case, the mean annual effective dose rate is 0.55 mSv/y, which is a little higher than world mean value i.e. 0.48 mSv/y (UNSCEAR, 2000; Hussain and Hussain, 2011), but is still higher.

Table 3. Absorbed dose rate, annual effective dose rate, radium equivalent activity, external hazard index.

Site #	Absorbed gamma dose rate in air (nGy/h)	Annual effective dose Rate (mSv/y)	Radium equivalent activity (Bq/kg)	External hazard index
1	77.24	0.47	159.17	0.43
2	84.51	0.52	173.76	0.47
3	90.34	0.55	183.27	0.49
4	90.5	0.55	183.64	0.5
5	87.3	0.54	177.88	0.48
6	90.92	0.56	184.73	0.5
7	99.3	0.61	201.85	0.55
8	93.88	0.58	190.93	0.52
9	99.28	0.61	201.46	0.54
10	87.57	0.54	176.54	0.48
11	90.29	0.55	186.03	0.5
12	83.39	0.51	170.44	0.46
13	79.55	0.49	161.75	0.44
14	92.62	0.57	187.66	0.51
15	103.72	0.64	212.67	0.57
16	90.61	0.56	185.86	0.5
17	103.16	0.63	210.68	0.57
18	88.16	0.54	178.55	0.48
19	68.31	0.42	138.08	0.37
Min.	68.31	0.42	138.08	0.37
Max.	103.72	0.64	212.67	0.57
Mean	89.51	0.55	182.37	0.49

3.4. Radium equivalent activity (Ra$_{eq}$)

Radium equivalent activity is calculated by considering the hazards that are connected with the use of building and other types of industrial materials containing ^{238}U, ^{232}Th and ^{40}K. Assuming that 10 Bq/kg of ^{238}U, 7 Bq/kg of ^{232}Th and 130 Bq/kg of ^{40}K generate approximately the equal amount of gamma-radiation, the total activity concentration of ^{238}U, ^{232}Th and ^{40}K is to be calculated. During calculation we use the following equation (Hussain and Hussain, 2011):

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \tag{4}$$

where A_U, A_{Th} and A_K denote activity concentrations for ^{238}U, ^{232}Th and ^{40}K, respectively. To avoid the expected risks of exposure, the material which contains more than 370 Bq/kg radium equivalent activity should not be used for industrial purposes (Dhawal et al., 2013; Alaamer, 2008). From Table 3 can be observed that the mean

value of radium equivalent activity according to our results equals to 182.37 Bq/kg, which is less than above mentioned recommended maximum value.

3.5. External hazard index (H$_{ex}$)

One of the characteristics of irradiation risk for the population is considered the so called external hazard index, which is calculated in the following way (Hussain and Hussain, 2011):

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \tag{5}$$

where A$_U$, A$_{Th}$ and A$_K$ are activity concentrations of ^{238}U, ^{232}Th and ^{40}K, respectively. To avoid the expected risks the external hazard index should be less than 1, which corresponds to maximally admissible radium equivalent activity 370 Bq/kg (Hussain and Hussain, 2011; Kessaratikoon and Awaekechi, 2008). According to results given in Table 3, in our case the mean value of external hazard index is 0.49, which is less than the above recommended limit.

3.6. Correlations

Figs. 4 and 5 graphically presents the correlations of radionuclide concentrations (contents) ^{232}Th/^{238}U and ^{232}Th/^{40}K.

Fig. 6 shows the correlation of annual effective dose rates with parent rocks according to sampling sites. In the results presented it can be observed increased concentrations. For instance, an increased concentration of ^{238}U isotope is at site 15, which is one of the main water catchment areas.
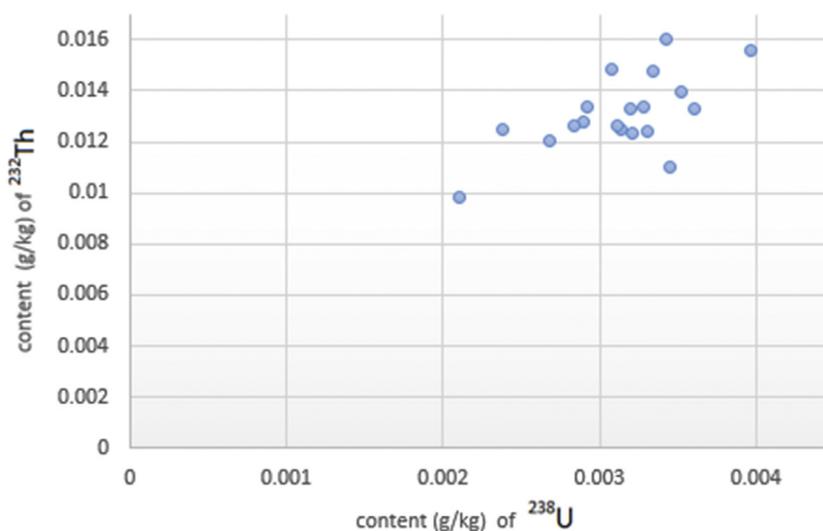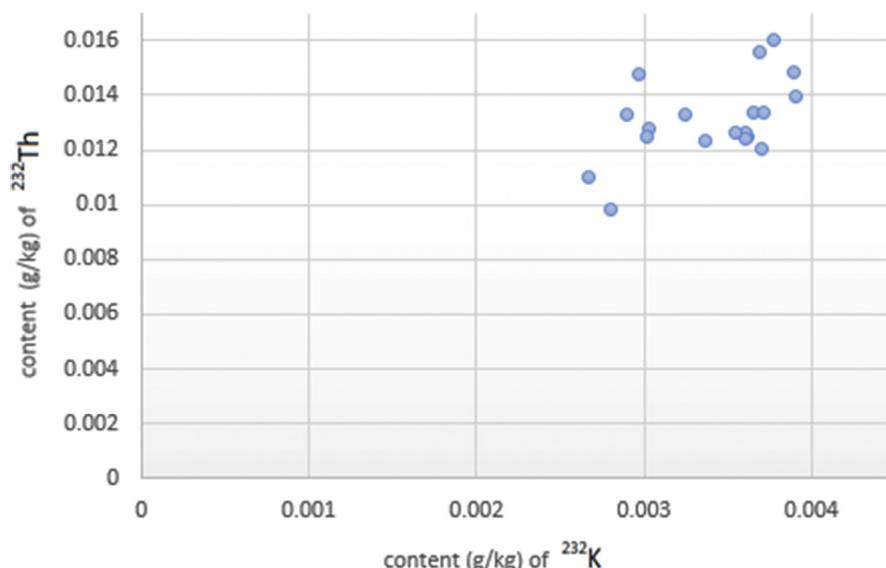

Fig. 4. Correlation — ^{232}Th/^{238}U.

Fig. 5. Correlation $-$ ^{232}Th/^{40}K.

Fig. 7 shows the correlation of ^{238}U, ^{232}Th and ^{40}K natural radionuclide concentrations with absorbed dose rates in the air according to sampling sites.

With the aim of taking into consideration geochemical factor during the process of soil formation, Digital Elevation Model (DEM) of the relief in a geo-informational system ArcGIS 10.4.1 has been developed, water flow has been modeled and a combined scheme of natural radionuclide distribution in the soil and geological structure have been created (Fig. 8).
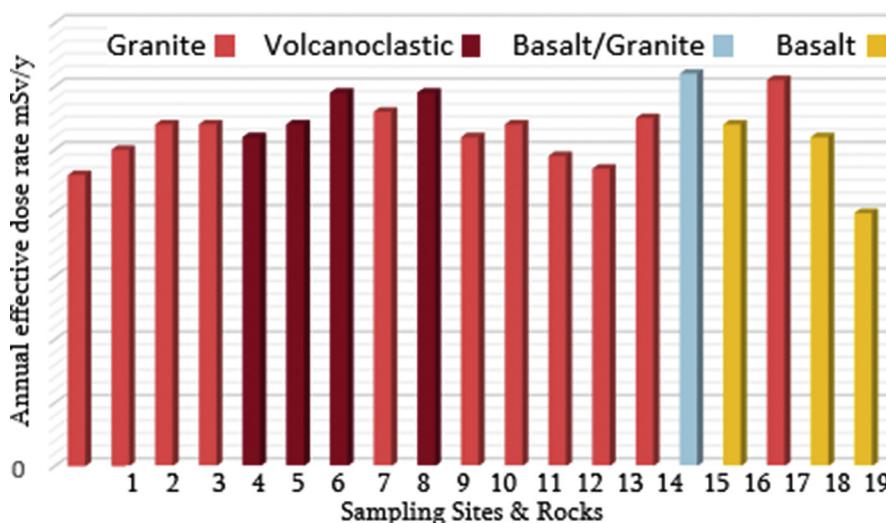
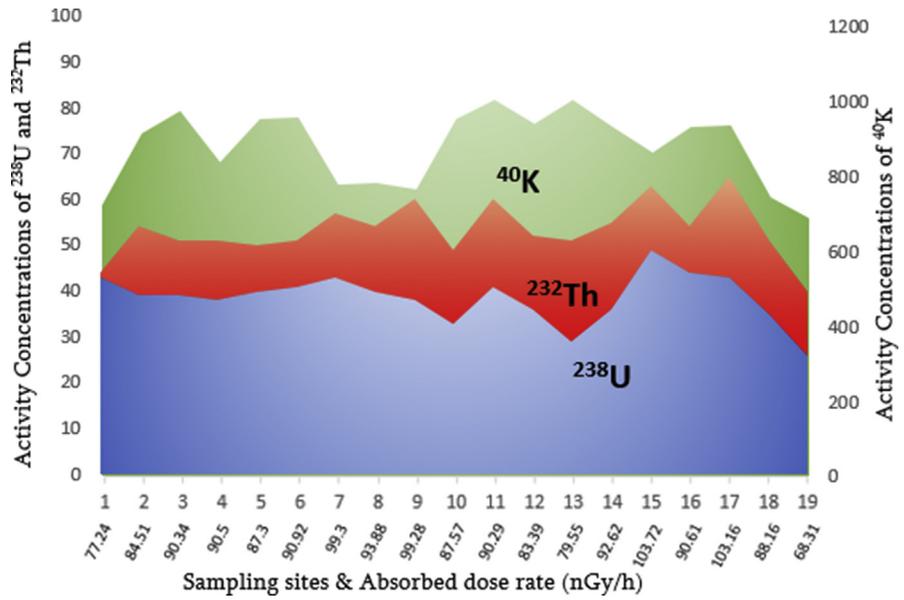**Fig. 6.** Correlation between annual effective dose and lithology of the area.

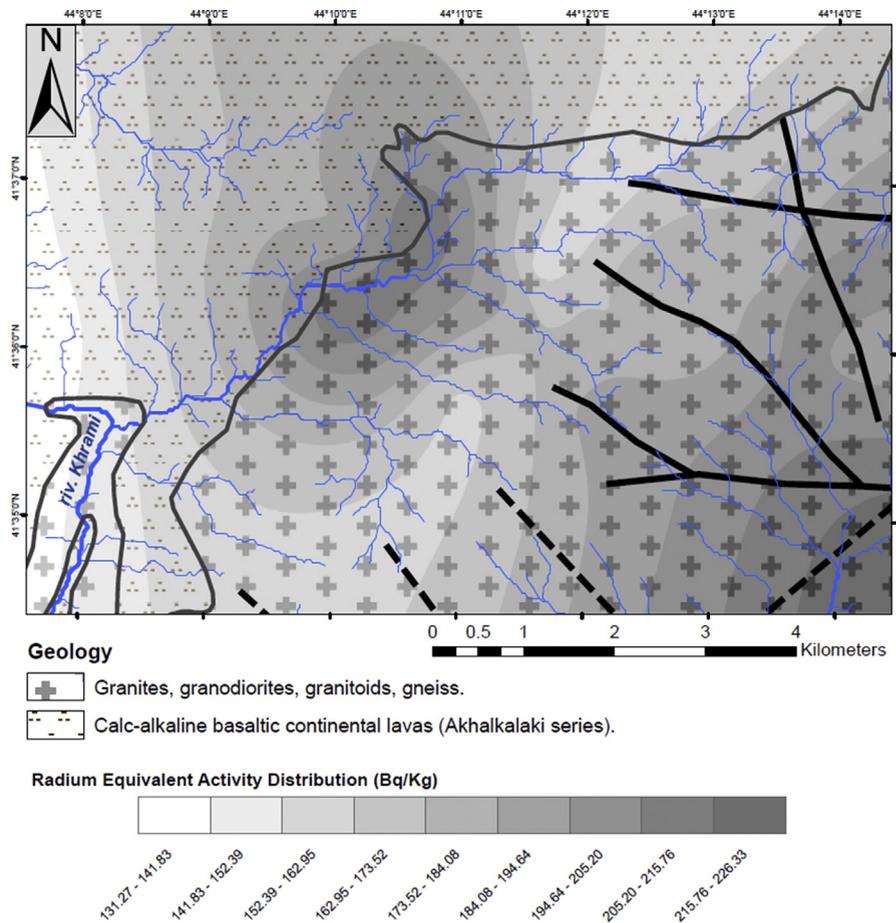**Fig. 7.** Correlation between activity concentrations and absorbed dose rate.

Fig. 8. Interconnection of radium equivalent activities, soil parent materials and water flows.

4. Discussions

As it can be seen from Fig. 8, the increased concentrations of natural radionuclides are in a certain correlation with the direction of water flows. Increased concentrations can be observed at their gathering points. Besides, as the combined scheme shows, the distribution of natural radionuclides are obviously related to the type of parent rock. Namely, the soils emerged at the expense of Late Variscan granitoids of Khrami massif, more apparently reveal higher natural radioactivity compared to Neogene and Quaternary lavas.

Mean value of **absorbed dose rate** in the air calculated according to natural radio-nuclide concentrations in the soil, in our case equals to 89.51 nGy/h. The obtained result is considerably higher (by 32.5 nGy/h) than the world mean value (Fig. 9), which is 57 nGy/h (UNSCEAR, 2000; Dhawal et al., 2013). But as it was mentioned above, our research covers Khrami massif, and where due to the spread of granitoids natural radioactive factors must have been increased.

Mean value of **annual effective dose rate** of 0.55 mSv/h is slightly higher than the world mean value (Fig. 10), which is 0.48 mSv/h (UNSCEAR, 2000; Hussain and Hussain, 2011). But the obtained value is less than the recommended limit established by ICRP which is 1 mSv/h (Dhawal et al., 2013; Hussain and Hussain, 2011). However, as it is known during the formation of the total radiation hazard, to gamma radiation portion generated by natural radionuclides is added some other significant components such as: the portion caused by the spread of artificial pollutants, cosmic radiation, radon inhalation, spread of natural and artificial pollutants and their concentration in drinking water and food, as well as professional activities, radiation impact in medical sphere etc (UNSCEAR, 2000).
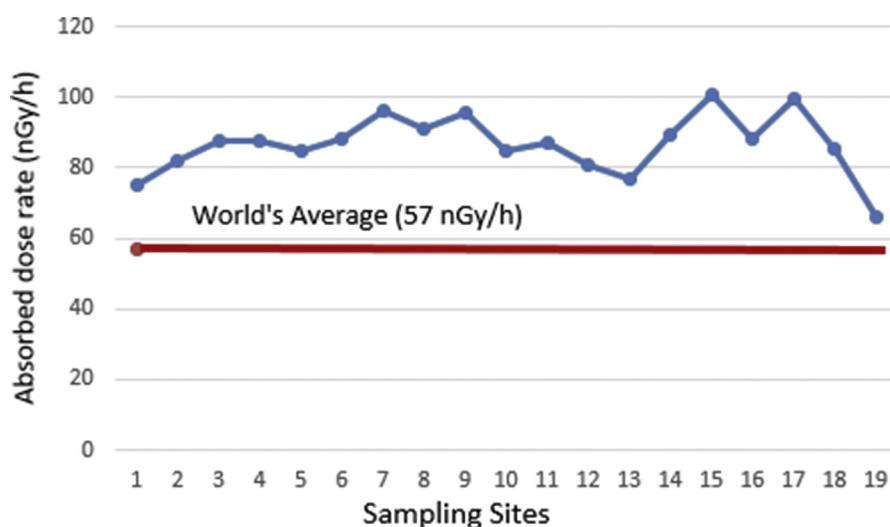

Fig. 9. Comparison of obtained values of absorbed dose rate with world mean values.
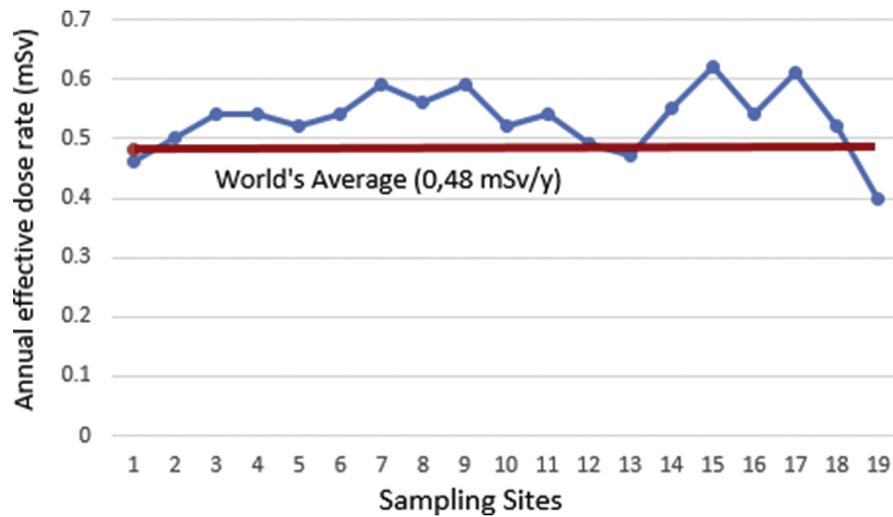
Fig. 10. Comparison of obtained values of annual effective dose rate with world mean values.

Mean value for **radium equivalent activity** according to our results is 182.37 Bq/kg, which is less than maximally admissible limit set by UNSCEAR, which is 370 Bq/kg (UNSCEAR, 2000). This indicates that the territory under this research is free from the threats caused by radium and its decay product radon, especially that there are no regional deep faults on the territory (Geological map, 1995).

For **external radiation index** all mean values are below 1, which means that the populated localities on the territory is not exposed to radiation hazard that exceeds the limit.

Fig. 11. The 9th site of sampling.

The maximum concentration of ^{137}Cs (33 Bq/kg) was fixed at the 9th site (Table 2, Fig. 11), with maximum value of elevation (AMSL) (Table 1). Table 4 compares the results for ^{137}Cs with the studies conducted in various countries. As shown in Table 4 in a number of cases ^{137}Cs concentration is relatively high, which in our opinion indicates the trace left after the Chernobyl 1986 accident and nuclear tests during the "Cold War" period. In general, the spread and sedimentation of artificial pollutants (radioisotopes) during the Chernobyl accident fallout depended on the strength of atmospheric motions and their directions. However, due to relatively high intensity of precipitation, pollution in mountainous regions was higher than in the plain, which is proved by corresponding studies carried out for instance, in France and Poland (Chareyron, 2002; Kubica et al., 2002).

Results of the research have shown that concentrations of natural radionuclide in the soils of the area under study considerably differ. In our opinion this must be conditioned by specific character of soils and their formation in which the forming parent rock play a significant role and the factor of geochemical migration of

Table 4. Comparison of current results for concentrations of^{137}Cs with data available in literature.

#	Country	Bq/kg	References
1	Ordu, Turkey	67.4−275.3	Çelik et al. (2010)
2	Venezuela	5.00	LaBrecque (1994)
3	Bangladesh	7	Miah et al. (1998)
4	Majorca (Spain)	10−60	Gomez et al. (1997)
5	Inshass, Cairo (Egypt)	1.6−19.1	Higgy and Pimpl (1998)
6	Algeria	15−35	Noureddine et al. (1997)
7	Louisiana (USA)	5−58	Karakelle et al. (2002)
8	Montenegrin coast (Yugoslavia)	1.5−28.4	Vukotic et al. (1998)
9	Sudan	0−18.5	Sam et al. (1997)
10	North-western Libya	0.9−1.7	Shenber (2001)
11	Riyadh (Saudi Arabia)	0−2	Al-Kahtani et al. (2001)
12	Northern Taiwan	1.48−27	Wang et al. (1997)
13	Punjab province (Pakistan)	2.80	Tahir et al. (2005)
14	Pakka Anna, Pakistan	3.60	Tufail et al. (2006)
15	Southern part of Punjab, Pakistan	1.60	Fatima et al. (2008)
16	Mid-Rechna, Pakistan	3.50	Jabbar et al. (2010)
17	Punjab Province, Pakistan	2.18	Rahman et al. (2011)
18	Kohistan, Pakistan	9.49	Hassan M Khan et al. (2011)
19	Mirpur Azad Kashmir	1.39	Rafique (2014)
20	Khrami Massif, Georgia	10.65	Present study

substances is less important. Research results have indirectly revealed that sialic igneous rocks of Khrami massif, namely the soils that have emerged as a result of weathering of granitoids are indeed characterized by relatively high concentrations of natural radionuclides.

Based on the research, terrestrial background radiation of a specific region has been studied for the first time in Georgia, taking into account its geological and geographical peculiarities. Despite the fact that the research has shown relatively high characteristics of radioactivity in the soils, exposure of the population to radiation hazards as a result of assessment is lower than internationally permissible limits and recommendations.

The research and methodology can be used in other similar studies to be carried out in Georgia, as well as other regions of south Caucasus, which will favor the further creation and development of a single analytical and information database on the current situation in south Caucasus regarding terrestrial radioactivity and in general, radiation hazard safety.

Declarations

Author contribution statement

Kakhaber Kapanadze: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Archil Magalashvili: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Platon Imnadze: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

Al-Kahtani, S.A., Farouk, M.A., Ai-Zahrani, A.A., 2001. Radioactivity levels in soil of three selected sites at and around Riyadh City. J. Radioanal. Nucl. Chem. 250, 93–95.

Alaamer, A.S., 2008. Assessment of human exposures to natural sources of radiation in soil of Riyadh, Saudi Arabia. Turk. J. Eng. Environ. Sci. 32 (4), 229–234.

Çelik, Necati, Damla, Nevzat, Çevik, Uğur, 2010. Gamma ray concentrations in soil and building materials in Ordu, Turkey. Radiat. Effects Defects Solids 165, 1–10.

Chareyron, B., 2002. Chernobyl fallout over France/the specific situation of the alpine environment. Publ. .Int. J. Radiat. Med. 4 (1-4), 163–172.

Dhawal, S.J., Kulkarni, G.S., Pawar, S.H., 2013. Terrestrial background radiation studies in South Konkan, Maharashtra, India. Int. J. Radiat. Res.h 11 (4), 263–270.

Fatima, I., Zaidi, J.H., Arif, M., Daud, M., Ahmad, S.A., Tahir, S.N.A., 2008. Measurement of natural radioactivity and dose rate assessment of terrestrial gamma radiation in the soil of southern Punjab. Radiat. Prot. Dosim. 128, 206-212.

Pruidze, M.P., Gamkrelidze, M.I., 1995. Geological Map of Bolnisi Mine Region (K-38-89-А,б). Geological Foundations of Georgia, №18933.

Gomez, E., Garcias, F., Casas, M., Cerda, V., 1997. Determination of ^{137}Cs and ^{90}Sr in Calcareous soils: geographical distribution on the Island of Majorca. Appl. Radiat. Isot. 48, 699–704.

Higgy, R.H., Pimpl, M., 1998. Natural and man-made radioactvity in soils and plants around the research reactor of Inshass. Appl. Radiat. Isot. 49, 1709–1712.

Hussain, R.O., Hussain, H.H., 2011. In: Singh, Nirmal (Ed.), Natural Occurring Radionuclide Materials, Radioisotopes – Applications in Physical Sciences. InTech.

Jabbar, A., Arshed, W., Bhatti, A.S., et al., 2010. Measurement of soil radioactivity levels and radiation hazard assessment in mid Rechna interfluvial region, Pakistan. J. Radioanal. Nucl. Chem. 283, 371.

Karakelle, B., Öztürk, N., Köse, A., et al., 2002. Natural radioactivity in soil samples of Kocaeli basin. Turk. J. Radioanal. Nucl. Chem. 254, 649.

Kessaratikoon, P., Awaekechi, S., 2008. Natural radioactivity measurement in soil samples collected from municipal area of Hat Yai district in Songkhla province, Thailand. KMITL Sci. J. Sect. A 8, 52−58.

Khan, Hasan M., Ismail, M., Khan, K., Akhter, P., 2011. Radioactivity levels and gamma-ray dose rate in soil samples from Kohistan (Pakistan) using gamma-ray spectrometry. Chin. Phys. Lett. 28 (1), 019301.

Kubica, B., Mietelski, J.W., Gołaś, J., Skiba, S., Tomankiewicz, E., Gaca, P., Jasińska, M., Tuteja-krysa, M., 2002. Concentration of ^{137}Cs, ^{40}K, ^{238}Pu and $^{239+240}$Pu radionuclides and some heavy metals in soil samples from two main valleys from Tatra National Park. Pol. J. Environ. Stud. 11 (No. 5), 537−545.

LaBrecque, J.J., 1994. Distribution of ^{137}Cs, ^{40}K, ^{238}U and ^{232}Th in soils from Northern Venezuela. J. Radioanal. Nucl. Chem. 178, 327.

Miah, F.K., Roy, S., Touhiduzzaman, M., Alam, B., 1998. Distribution of radionuclides in soil samples in and around Dhaka city. Appl. Radiat. Isot. 49, 133−137.

Noureddine, A., Baggoura, Benaissa, Larosa, J.J., Vajda, N., 1997. Gamma and alpha emitting radionuclides in some Algerian soil samples. Appl. Radiat. Isot. 48, 1145−1148.

Rafique, Mir Khawaja, 2014. Cesium-137 activity concentrations in soil and brick samples of Mirpur, Azad Kashmir; Pakistan. Iran. J. Radiat. Res. 12, 39−46.

Resolution #35 of the Government of Georgia, 3 January 2014. Rules of sampling for control of wastes of pesticides and agrochemicals in food, animal food and environmental objects. Tbilisi.

Sam, K., Ahmed, M.M.O., El Khangi, F.A., El Nigumi, Y.O., Holm, Eldar., 1997. Assessment of terrestrial gamma radiation in Sudan. Radiat. Protect. Dosim. 71, 141−145.

Shenber A, M., 2001. Fallout ^{137}Cs in soils from North Western Libya. J. Radioanal. Nucl. Chem. 250, 193−194.

Shekelashvili, E., Razmadze, M. (Eds.), 1999. Soil Map of Georgia. JSC "Cartography", Tbilisi.

Tahir, S.N.A., Jamil, K., Zaidi, J.H., Arif, M., Ahmed, N., Ahmad, S.A., 2005. Measurements of activity concentrations of naturally occurring radionuclides in soil samples from Punjab province of Pakistan and assessment of radiological hazards. Radiat. Protect. Dosim. 113, 421-427.

Tufail, M., Akhtar, N., Waqas, W., 2006. Measurement of terrestrial radiation for assessment of gamma dose from cultivated and barren saline soils of Faisalabad in Pakistan. Radiat. Meas. 41, 443−451.

UNSCEAR, 2000. United Nations Scientific Committee on the Effects of Atomic Radiation. (2000). Annex B. Exposures from Natural Radiation Sources (New York: USA).

Ur-Rahman, Saeed, Matiullh, Matiullah, Malik, Fariha, Mir, Rafique, Anwar, Khawaja, Javaid, Ziafat, M., Jabbar, Abdul, 2011. Measurement of naturally occurring/fallout radioactive elements and assessment of annual effective dose in soil samples collected from four districts of the Punjab Province, Pakistan. J. Radioanal. Nucl. Chem. 287, 647−655.

Vukotic, P., Borisov, I., Kuzmič, V., Antović, N., Dapčević, S., Uvarov, V., Kulakov, V., 1998. Radioactivity on the Montenegrin Coast, Yugoslavia. J. Radioanal. Nucl. Chem. 235, 151−157.

Wang, C.J., Lai, S.Y., Wang, J.J., Lin, Y.M., 1997. Transfer of radionuclides from soil to grass in Northern Taiwan. Appl. Radiat. Isot. 48, 301−303.