Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 27(2), 2024, pp. 37 - 47

^{222}Rn Concentration Levels in Soil Gas and Water in Kvemo Kartli Region, Georgia - ^{222}Rn Mapping

[1]Nino A. Kapanadze, [1]George G. Melikadze, [1]Aleksandre Sh. Tchankvetadze, [1]Tamar T. Jimsheladze, [1]Zviad I. Magradze, [2]Shota D. Gogichaishvili, [1]Marina Sh. Todadze, [1]Elene V. Chikviladze, [2]Lia T. Chelidze

[1]M. Nodia Institute of Geophysics of the I. Javakhishvili Tbilisi State University, Georgia,
[2]E. Andronikashvili Institute of Physics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

[1]e-mail: ninokapanadze@gmail.com

ABSTRACT

Within the framework of the SRNSFG FN-19-22022 project "^{222}Rn mapping and Radon risk assessment in Georgia", the authors carried out fieldwork to quantify the ^{222}Rn distribution in water and soil gas as well as to ascertain geological factors influencing the ^{222}Rn concentration levels in some geographical areas of Georgia. On-site ^{222}Rn concentration has been measured in soil gas (68 sampling points) and in various water sources (boreholes and springs, 75 water points, 66- springs, 9 boreholes) using AlphaGUARD PQ2000 PRO (Saphymo GmbH) Radon monitor. The ^{222}Rn concentration ranged from 0.12 to 73 Bq/L in water and up to 36.9 Bq m^{-3} in soil gas. All observation sites were marked by GPS position. The data underwent basic statistical analysis and were visualized using various plots. Subsequently, the field data were digitized and integrated into a GIS system, which highlighted the ^{222}Rn distribution in water and soil gas on the territory of Kvemo Kartli.
Key words: *Rn mapping, soil gas, water, GIS, Kvemo Kartli, Georgia*

Introduction

Following the aims and tasks of the SRNSFG FN-19-22022 project "Radon mapping and Radon risk assessment in Georgia", during 2020-2022, the authors carried out fieldwork in order to quantify the ^{222}Rn distribution, ascertain geological factors influencing the ^{222}Rn concentrations in indoor air, water and soil gas in different geographical areas of Georgia. With the project Georgia joined the countries that carry out systematic Radon (^{222}Rn) surveys in indoor air, soil gas and water. In Georgia, ^{222}Rn mapping in soil gas has included ten regions. ^{222}Rn concentrations obtained in the Kvemo Kartli region are presented and discussed in this paper. Of 143 locations, In soil gas, ^{222}Rn concentration was measured in 68 locations and in water in 75 locations with AlphaGUARD monitor. For all observation sites, the geochemical properties have been characterised, and their coordinates in GPS recorded.

The works [10-11, 13-14] present the results of our early studies of ^{222}Rn content in soil gas and water in various regions of the country.

Geological and lithological data of the study area

Kvemo Kartli, located in the southeastern part of Georgia, is a region distinguished by its diverse geology and lithology, shaped by tectonic, volcanic, and sedimentary processes. Situated within the tectonic framework of the Lesser Caucasus, the region exhibits complex geological characteristics [1-2].

The area is dominated by volcanic rocks, including basalts, andesites, and tuffs, which are remnants of ancient volcanic activity. Intrusive rocks such as granites and diorites are also present, formed through deep-seated magmatic processes. These rocks frequently contain elevated levels of uranium and thorium, whose radioactive decay produces ^{222}Rn gas. As a result, areas with volcanic and intrusive rocks are potential ^{222}Rn hotspots.

Sedimentary formations in Kvemo Kartli include limestones, sandstones, shales, and marls. These rocks typically exhibit lower uranium content than igneous rocks, which reduces their ^{222}Rn -emission potential. The region also features conglomerates, indicative of high-energy river activity during their deposition. Additionally, river valleys and plains in Kvemo Kartli are dominated by quaternary alluvial and fluvial deposits, consisting of clays, silts, sands, and gravels, reflecting dynamic sedimentary processes.
Soils derived from ^{222}Rn -rich parent rocks, such as volcanic or granitic materials, may contribute to higher ^{222}Rn emissions. Loose and porous soils, such as those from alluvial and fluvial deposits, can facilitate the upward migration of ^{222}Rn to the surface.

Kvemo Kartli's tectonic setting includes active faults and fractures, which serve as conduits for 222Rn gas. Areas near fault lines often exhibit elevated ^{222}Rn concentrations due to the migration of gas from deeper geological layers. Groundwater flow in aquifers can either trap ^{222}Rn or transport it to the surface. Volcanic rock aquifers may have higher ^{222}Rn levels due to dissolved ^{222}Rn in groundwater [3-4].
Homes and buildings located in ^{222}Rn -prone areas, particularly those with poor ventilation and direct contact with the ground, are at risk of experiencing elevated indoor ^{222}Rn concentrations.

Measurement methodology

Measurements in Water

The field study was carried out by the mobile groups of researchers using an AlphaGUARD PQ 2000 PRO (hereafter “AlphaGUARD monitor”) portable ^{222}Rn monitor based on the measurement principle of the pulse ionization chamber [2]. The instrument measures ^{222}Rn concentrations in air, soil gas as well as in water. For water samples, the AquaKIT was used [3], consisting of the following components: AlphaGUARD monitor, degassing vessel, security vessel and AlphaPUMP [4] (Fig. 1). The components were connected in a closed circuit, and ^{222}Rn concentration was measured according to the manual’s protocol [5-7]. First, the water sample was collected from the source in a plastic bottle, which was filled entirely and closed tightly in order to avoid ^{222}Rn escape from the sample. Second, the water sample was injected into the degassing vessel. The AlphaPUMP was turned on for 10 minutes with a flow rate of 0.3 L/min for degassing ^{222}Rn from water to air. After turning it off, the AlphaGUARD monitor remained on for 20 minutes to carry out the measurements. As a final value for determining ^{222}Rn concentration in the sample, the indicated mean value in Bq/m3 on the monitor screen was taken.

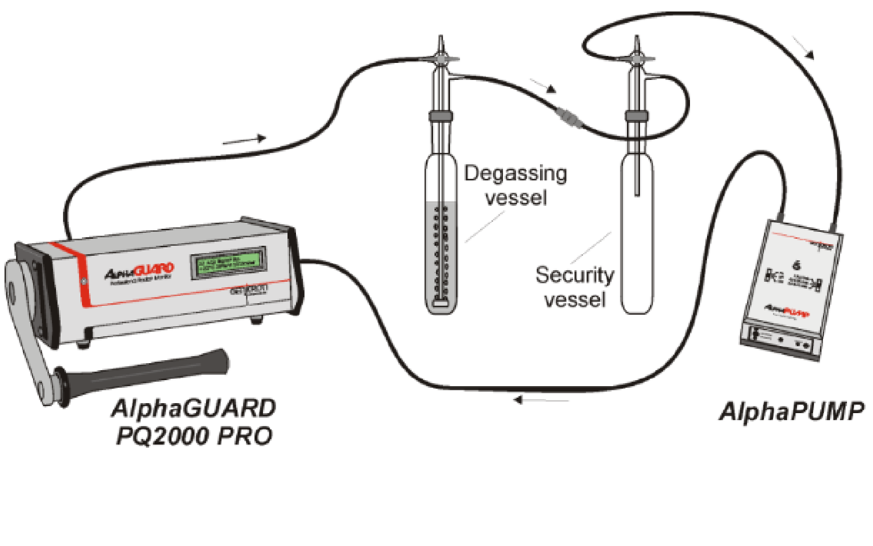


Fig. 1. AquaKIT measurement set-up [6].

The ^{222}Rn activity concentration in the water sample was calculated by equation (1), which considers the ^{222}Rn quantity diluted by the air within the measurement set-up as well as remains diluted in the watery phase [8]:

$$c_{Water} = \frac{c_{Air} \times \left(\frac{V_{System} - V_{Sample}}{V_{Sample}} + k\right) - c_0}{1000} \quad (1)$$

where:

c_Water = ^{222}Rn concentration in water sample [Bq/L],

c_Air = ^{222}Rn concentration [Bq/m3] in the air of the circuit,

c_0 = ^{222}Rn concentration before sampling (zero level) [Bq/m3],

V_System = interior volume of the circuit [in our case 1.102 L],

V_Sample = volume of the water sample [in our case 0.1 L],

k = ^{222}Rn distribution coefficient [0.26, since the measurements were performed in the temperature range 10-30 °C].

As a rule, the measurements followed the sampling with minimum delay. In case of delayed measurement, equation (2) was applied:

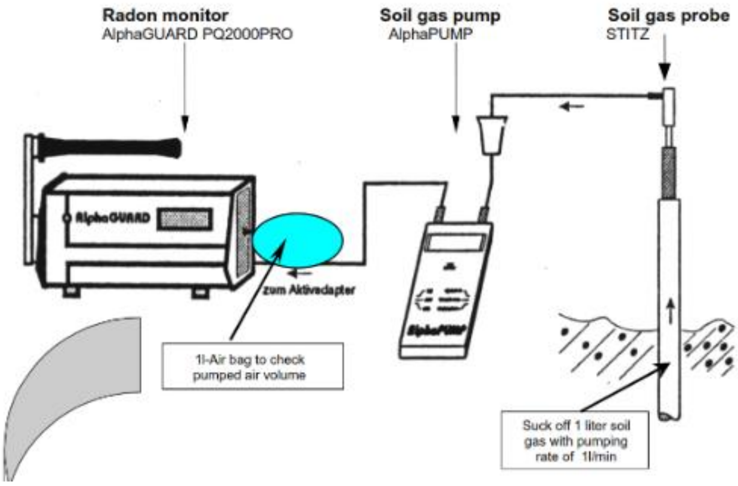
$$C_0 = C \times e \frac{ln2}{t_{1/2}} \Delta t \quad (2)$$

where, C_0 is the value at the moment of sampling, C is the measured value, t_(1/2) is a half-life of Czech Geological Survey. Praha, Rn, Δt is the time delay between sampling and measurement.

Measurements in Soil gas

The ^{222}Rn concentration measurements in soil gas were performed in the vicinity of every sampled water source and in the additional points without water sources to obtain dense coverage of the area. For the measurement, the soil gas exterior probe (STITZ-by Geophysik GCD Leipzig) was used. The closed circuit was set as follows: soil gas probe, AlphaPUMP, AlphaGUARD monitor and ^{222}Rn progeny filter (Fig. 2a), following the user manual [8]. The soil gas probe, locked at the rivet at the tip, was hammered into the ground approximately to the depth of 0.7-1.0 m. The AlphaGUARD monitor and AlphaPUMP were set to flow mode with a 1 min cycle and flow rate of 1 L/min, respectively. The quantity of gas and the filling time of the ionization chamber were assessed with the 1-litre balloon attached to the air outlet nozzle of the AlphaGUARD monitor (Fig. 2b). Only the soil gas samples, with an extraction duration of less than 3 min, were measured. After completing the waiting time of 10 minutes for the decaying of the thoron, the measurement process continued for 20 min. As a final result, the mean value of the ^{222}Rn concentration indicated on the monitor screen in Bq/m3 was considered.

a)



b)

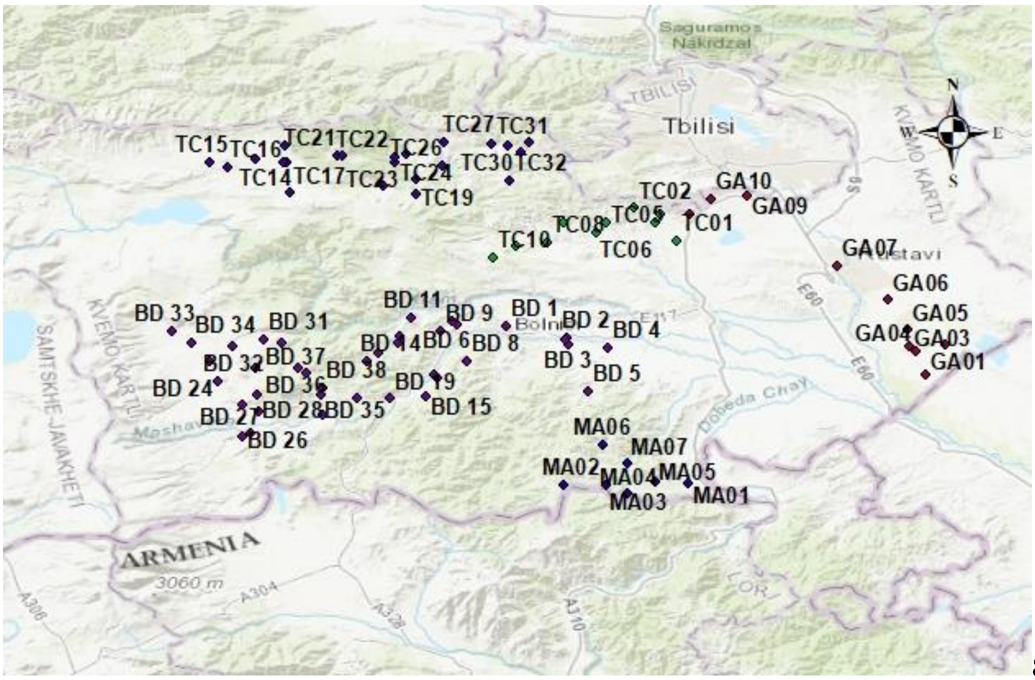
Fig. 2. a) Schematic view of soil gas measurement setup [8]; b) Measurement by AlphaGUARD, AlphaPUMP and 1-L balloon attached to the air outlet nozzle of the AlphaGUARD

The ^{222}Rn survey was conducted during favorable environmental conditions, and the days with snow cover and precipitation were avoided.

All observation sites were marked by GPS position. Results of analyses on ^{222}Rn concentration were marked on topographic and geological maps. In order to figure out the connection of ^{222}Rn anomalies to geological and hydro-geological structures, the field data were digitized and transferred into the GIS system.

Data calculation and results

All 143 observation sites were marked by GPS position. Results of analyses on 222Rn concentration were marked on topographic and geological maps. In order to figure out the connection of 222Rn anomalies to geological and hydro-geological structures, the field data were digitized and transferred into the GIS system for further analysis (Fig. 3).



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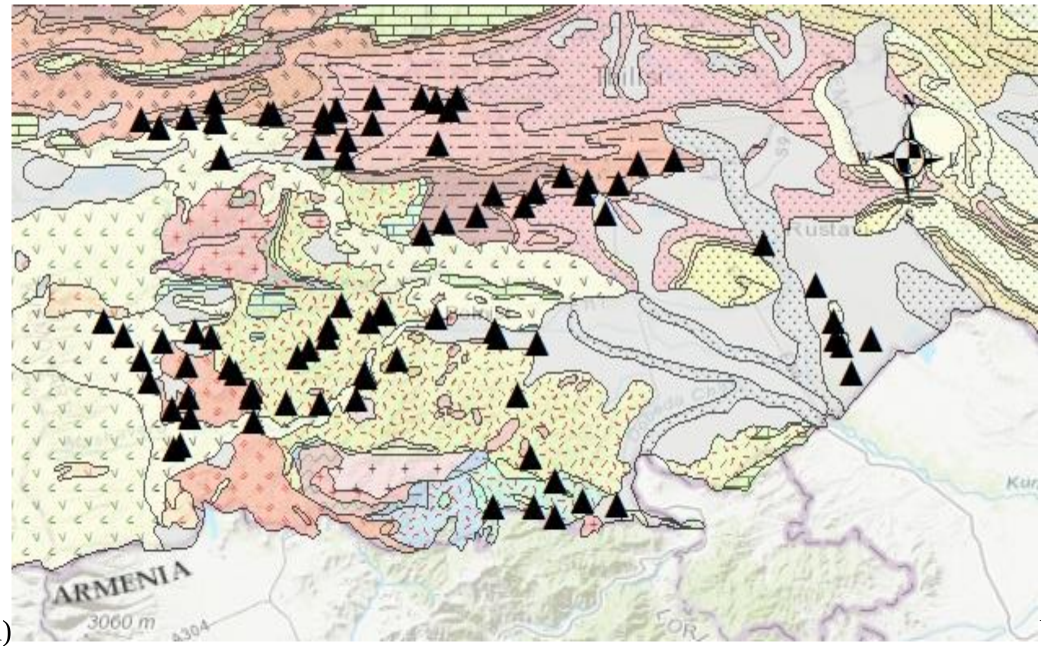
a)  b)

Fig. 3. Location of sampled water and soil gas points on (a) a topographic map and (b) a geological map [9] of the Shida Kartli area.

Measured ^{222}Rn concentrations in water and soil gas are provided in Table 1.

Table 1. ^{222}Rn concentration values of samples water and soil gas points, Kvemo Kartli.

N	Water point Type	Water, Soil gas	Name of location	Rn(w) Bq/L	Rn(G) kBq/m3
Bd1		Rn_W/S	Ratevani	8.95	6.53
Bd2	mineral	Rn_W/S	Rachisubani	0.81	9.49
Bd3	well	Rn_W/S	Samtredo	0.37	20.6
Bd4	spring	Rn_W/S	Savaneti	15.57	12.1
Bd5	spring	Rn_W/S	Talavari	6.95	8.72
Bd6		Rn_W/S	Akaurta	7.01	13.2
Bd8	spring	Rn_W/S	MuSevani	33.76	23.9
Bd9	spring	Rn_W/S	Kvemo KveSi	15.10	9
Bd10	spring	Rn_W/S	Tandzia	20.51	11.8
Bd11	spring	Rn_W/S	Bertakari	5.30	16.2
Bd12	spring	Rn_W/S	Tsipori	12.01	3.1
Bd13	spring	Rn_W/S	Darbazi	20.20	5.83
Bd14	spring	Rn_W/S	Darbazi 2	0.47	22.1
Bd15	spring	Rn_W/S	Balicha	15.26	14.7
Bd18		Rn_S	Kazreti		14.3
Bd19	spring	Rn_W/S	Didi Dmanisi	42.60	0.276
Bd20	spring	Rn_W/S	Boslebi	34.54	27.1
Bd21	well	Rn_W/S	Gantiadi	2.24	6.02
Bd22		Rn_S	Iakublo		7.71
Bd24	spring	Rn_W/S	Karabulakhi	9.29	7.52

Bd28	spring	Rn_W/S	Dagarakhlo	9.98	12.8
Bd29	spring	Rn_W/S	Dagarakhlo 2	1.09	2.05
Bd30	spring	Rn_W/S	Saja	18.70	12.1
Bd32	spring	Rn_W/S	Kvemo Karabulakhi	8.71	19.7
Bd35	spring	Rn_W/S	Kizilqilisa	28.90	19.3
Bd36		Rn_W/S	Ormasheni	17.76	15.2
Tc1	spring	Rn_W/S	Koda	8.48	3.53
Tc2	spring	Rn_W/S	Goubani	13.19	27.1
Tc3	spring	Rn_W/S	Borbalo	9.48	7.46
Tc4	spring	Rn_W/S	Vashlovani	14.74	5.76
Tc5	well	Rn_W/S	AsureTi	8.38	22.3
Tc6		Rn_S	EnageTi		22
Tc7	spring	Rn_W/S	Ardisubani	1.56	2.28
Tc8	spring	Rn_W/S	Sagrasheni	14.63	8.86
Tc10		Rn_S	TeTritskaro		10.8
TC11	Spring	Rn W/S	Arjevani	0.15	3.86
TC12	spring	Rn W/S	Cholmani	21.52	4.43
TC13		RnW/S	Livadi	5.27	6.3
TC15	spring	Rn W/S	Tijisi	4.48	1.8
TC16	spring	Rn W/S	Sabechisi	6.60	1.87
TC17		Rn S	Tsalka		1.95
TC18	spring	Rn W/S	Akhalsofeli	3.19	32
TC19		Rn S	Sapudzvrebi		29.5
TC20	spring	Rn W/S	Algeti	13.19	11.2
TC21	spring	Rn W/S	Chinchriani	1.78	10.8
TC23	spring	Rn W/S	Shekhvetila	0.56	18.4
TC24	spring	Rn W/S	Manglisi	51.35	15.6
TC26	spring	Rn W/S	Didi Toneti	0.80	14.1
TC27	spring	Rn W/S	Mokhisi	10.71	1.23
Tc28	spring	Rn W/S	Tskluleti	0.95	5.41
TC30	spring	Rn W/S	Vanati	4.64	4.59
TC31	spring	Rn W/S	Shamta	8.30	11.1
Tc32	spring	Rn W/S	Orbeti	2.94	6.45
MA01	spring	Rn W/S	Sadakhlo	0.68	2.3
MA02	spring	Rn W/S	Chamchakhi	0.21	1.72
MA03	spring	Rn W/S	At Armenian border	0.12	34
MA04	spring	Rn W/S	Khojorni	33.13	20.5
MA05	spring	Rn W/S	Tsopi	24.07	13.4
MA06	spring	Rn W/S	Tseraqvi	3.36	10.7
MA07	spring	Rn W/S	Jankhoshi	8.39	30.1
GA01	well	Rn W/S	Vakhtangisi	1.16	11.6
GA02	soil	Rn S	Jandara		4.01
GA05	soil	Rn S	Gardabani		1.76
GA06	soil	Rn S	Gardabani 2		21.6
GA07	spring	Rn W/S	Akhali Rustavi	12.87	5.29
GA08	spring	Rn W/S	Kumisi	4.68	36.9

GA09	spring	Rn W/S	ქვემო თელეთი, წყარო	38.20	26.8
GA10	spring	Rn W/S	Zemo Teleti	1.10	17.9

^{222}Rn in Water

In the Kvemo Kartli Region, ^{222}Rn in water sources was monitored at 75 points (66 spring and 9 borehole) in the period of May-October 2022 using the AlphaGUARD monitor and the AquaKIT, consisting of the following components: AlphaGUARD monitor, degassing vessel, security vessel and AlphaPUMP [7] (Fig. 1). The components were connected in a closed circuit, and ^{222}Rn concentration was measured according to the manual's protocol [6].

The ^{222}Rn activity concentration in the water sample was calculated by equation (1), which considers the ^{222}Rn quantity diluted by the air within the measurement set-up as well as remains diluted in the watery phase [6]. As a rule, the measurements followed the sampling with minimum delay. In case of delayed measurement, equation (2) was applied.

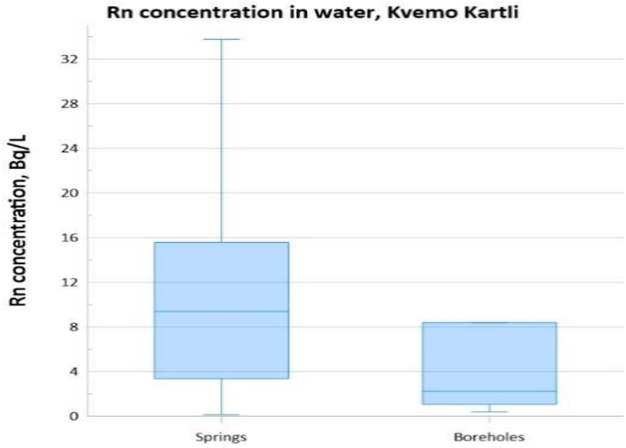
Although the dataset for our ^{222}Rn concentration data in water is limited, the basic statistical analysis for the sampled points is presented in the table 2. As noticed, arithmetic mean (AM) and geometric mean (GM) ^{222}Rn concentrations are lower in boreholes than in natural springs. ^{222}Rn concentration for all water points ranges from 0.12 to 73.50 kBq m-^{3} with AM of 12.43 kBq m^{-3}, The values are in the ranges obtained in our previous study [10]. One of the main factors contributing to the variation in ^{222}Rn concentrations is the influence of anomalously high values, which are caused by specific lithological features and the presence of local radioactive elements along the flow path from recharge to discharge areas. In our case, the ^{222}Rn levels are indicative of the geological characteristics of the water sampling sites. Although ^{222}Rn concentration values in water are generally not ideal for detailed statistical analysis, they still offer valuable insights into the underlying geological and hydrogeological processes.

Table 2. Basic statistics of ^{222}Rn concentration in water, Kvemo Kartli

		222Rn concentration / Bq/L						
Type	No. points	Min	Max	Median	AM	ASD	GM	GSD
All	75	0.12	73.50	8.71	12.43	13.40	6.04	4.36
Spring	66	0.12	73.50	9.38	12.86	13.44	6.60	4.18
Borehole	9	0.37	32.72	2.24	9.24	13.40	3.15	4.58

Type: Type of water point; No: number of measuring points; AM: arithmetic mean; ASD: arithmetic standard deviation; GM: geometric mean; GSD: geometric standard deviation; Min: minimum; Max: maximum.

For better visualization of ^{222}Rn concentrations, the values were represented using box plot graphs (Fig. 4). These graphs reveal that natural springs exhibit higher 222Rn concentrations compared to boreholes.



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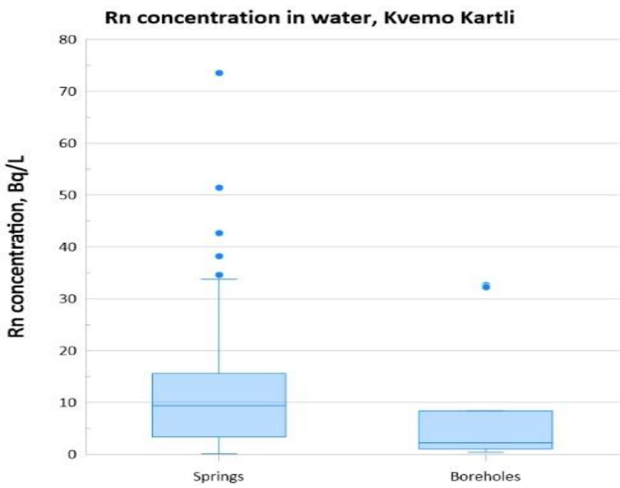

b)

Fig. 4. The distribution of ^{222}Rn concentrations in sampled springs and boreholes is illustrated in two ways: a) Including "outliers" to show the full range of variability. b) Excluding "outliers" to highlight the central trend and reduce the influence of extreme values.

^{222}Rn in soil gas

In the Kvemo Kartli Region, ^{222}Rn in soil gas was monitored at 68 points in the period of May-October 2022 in the vicinity of every sampled water source and in the additional points without water sources to obtain dense coverage of the area, using the AlphaGUARD monitor [2]. The closed gas cycle was set as follows: probe-AlphaPUMP-AlphaGUARD, including ^{222}Rn progeny filter and water break in accordance with the user manual [5; 7-8]. The soil gas probe, locked at the rivet at the tip, was hammered into the ground to approximately a depth of 0.7–1.0 m. The AlphaGUARD and AlphaPUMP were set to flow mode at 1 min (cycle = 1 min F) and 1 L min^{-1}, respectively. The volume of gas and the filling time of the ionization chamber were assessed with the 1-L balloon attached to the air outlet nozzle of the AlphaGUARD. Only the soil gas samples with an extraction duration of less than 3 min were measured. After a waiting time of 10 minutes, for short-lived radionuclides (thoron) to decay, the activity was measured for 20 min, and the mean value read was taken as the representative ^{222}Rn concentration. The measuring setup is shown in Fig. 2.

In general, the data on ^{222}Rn concentration in soil gas is not rich because the measurements are more demanding and complex than those in water and especially in indoor air [12].

Although the database of our ^{222}Rn concentration in soil gas is modest, the summary statistic of ^{222}Rn concentration in soil gas is given in Table 3. As noticed, arithmetic mean (AM) and geometric mean (GM) ^{222}Rn concentrations are lower than it is expected in volcanic rocks. ^{222}Rn concentration ranges from 0.28 to 36.90 kBq/m^3 with AM of 13.49 kBq /m^3, The values are in the ranges obtained in the previous study [7; 9-10]. One of the main factors which may cause the difference is soil permeability. Although volcanic rocks may have high porosity due to the presence of vesicles, their permeability is often constrained by a lack of connectivity among them [15-16].

Table 3. Basic statistics of ^{222}Rn concentration in soil gas in volcanic rocks, Kvemo Kartli

	^{222}Rn concentration, kBq·m^{-3}						
No	Min	Max	Median	AM	ASD	GM	GSD
68	0.28	36.90	11.15	13.49	11.02	8.65	2.91

No: number of measuring points; AM: arithmetic mean; ASD: arithmetic standard deviation; GM: geometric mean; GSD: geometric standard deviation; Min: minimum; Max: maximum

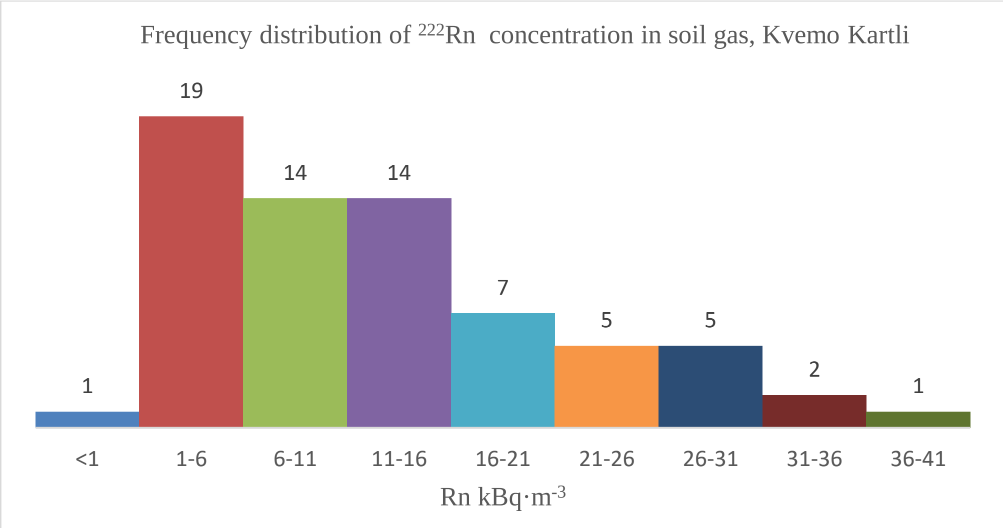

Fig. 5. Frequency distribution of ^{222}Rn concentration in soil gas, Kvemo Kartli.

Data, presented on the histogram plot (Fig. 5), show that the most of the measured concentrations, 19 values are 1-6 and 14-14 values are in the range of 6-11 and 16-21 kbq·m^{-3}.

Fig. 6 shows a cumulative frequency of ^{222}Rn concentrations.

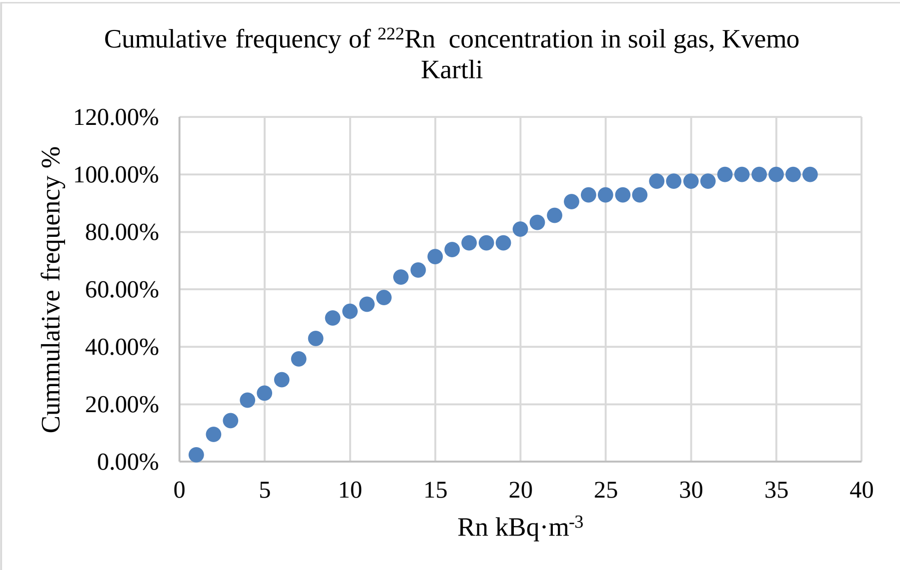

Fig. 6. Cumulative frequency of ^{222}Rn concentration

As seen from the figure, the values roughly fit a lognormal distribution. The values could be distinguished into 4 groups. The first group, in the region of >12 kBq m^{-3}, The 2nd group, in the region of 13-19 kBq·m^{-3}, the third, in the region of 20-27 kBq·m^{-3} and the 4th group 28-37 kBq·m^{-3}. Due to the wide range of permeability in volcanic and sedimentary rocks, such a result is expected [15-17], reflecting the area's geological structure.

Conclusion

From 143 ^{222}Rn measurements carried out and water points within the project *^{222}Rn mapping and ^{222}Rn risk assessment in Georgia*, in Kvemo Kartli region, 68 were in soil gas and 75 in water point. The arithmetic means of 13.49 ± 11.02 kBq·m^{-3} was obtained for ^{222}Rn concentration in soil gas and 12.43 ± 13.40 Bq/L, in water (for springs 12.86 ± 13.44 Bq/L and for boreholes 9.24 ± 13.40 Bq/L). The values in soil gas roughly fit a lognormal distribution. The values could be distinguished into 4 groups. The first group, in the region of >12 kBq m^{-3}, The 2nd group, in the region of 13-19 kBq m^{-3}, the third, in the region of 20-27 kBq m^{-3} and the 4th group 28-37 kBq·m^{-3}. The dataset for ^{222}Rn concentrations in water and soil gas is limited and provides only a general overview of Rn levels in the region. Therefore, further exploration of this area is recommended. Analyzing the existing ^{222}Rn data in water and soil gas, along with indoor air measurements and an evaluation of site characteristics and geochemical data, will enable a more comprehensive assessment of 222Rn risk to the population.

Acknowledgements. The paper is a part of the research done within the SRNSFG FN-19-22022 project "^{222}Rn mapping and ^{222}Rn risk assessment in Georgia". As recipients of the Research State Grant, the authors thank the Shota Rustaveli National Science Foundation of Georgia.

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^{222}Radon კონცენტრაციის დონეები ნიადაგსა და წყალში ქვემო ქართლის რეგიონში - ^{222}Rn-ის აგეგმვა

ნ. კაპანაძე, გ.მელიქაძე, ა.ჭანკვეტაძე, თ.ჯიმშელაძე,
ზ. მაღრაძე, შ. გოგიჩაიშვილი, მ. თოდაძე, ე.ჩიკვილაძე, ლ.ჭელიძე

რეზიუმე

SRNSFG FN-19-22022 პროექტის „რადონის აგეგმვა და რადონის რისკის შეფასება საქართველოში" ფარგლებში, საქართველოს რიგ გეოგრაფიულ ზონებში ჩატარდა საველე სამუშაოები როგორც წყალსა და ნიადაგში რადონის (^{222}Rn) განაწილების რაოდენობრივად განსაზღვრის მიზნით, ასევე რადონის კონცენტრაციების განმსაზღვრელი გეოლოგიური ფაქტორების შესაფასებლად. ადგილზე რადონის კონცენტრაცია გაზომილი იქნა ნიადაგის აირში (68 სინჯის აღების წერტილი) და სხვადასხვა წყალპუნქტებში (ჭები და წყაროები, სულ 75 წყალპუნქტი, 66- წყარო, 9 ჭაბურღილი) AlphaGUARD PQ2000 PRO (Saphymo GmbH) რადონის მონიტორის გამოყენებით. რადონის კონცენტრაცია მერყეობდა 0,12-დან 73 Bq/L წყალში და 36,9 Bq·m^{-3}-მდე ნიადაგის აირში. ყველა სადამკვირვებლო ადგილი მონიშნული იყო GPS პოზიციით. მონაცემები დამუშავდა საბაზისო სტატისტიკური ანალიზით და წარმოდგენილი იქნა სხვადასხვა გრაფიკების მეშვეობით. შემდგომში, ქვემო ქართლის ტერიტორიაზე წყალსა და ნიადაგის გაზში რადონის განაწილების ვიზუალიზაციისათვის მოხდა საველე მონაცემების აციფვრა და ინტეგრირება GIS სისტემაში.

საკვანძო სიტყვები: Rn-ის აგეგვმა, ნიადაგის აირი, წყალი, GIS, ქვემო ქართლი, საქართველო.

Уровни концентрации ^{222}Rn в почве и воде в регионе Квемо Картли, Грузия - картирование ^{222}Rn

Н. Капанадзе, Г. Меликадзе, А. Чанкветадзе, Т. Джимшеладзе, З. Маградзе, Ш. Гогичаишвили, М. Тодадзе, Е. Чиквиладзе, Л. Челидзе

Резюме

В рамках проекта SRNSFG FN-19-22022 «Картирование ^{222}Rn и оценка риска радона в Грузии» авторы провели полевые работы по количественной оценке распределения ^{222}Rn в воде и почвенном газе, а также по установлению геологических факторов, влияющих на уровни концентрации ^{222}Rn в некоторых географических районах Грузии. На месте концентрация ^{222}Rn была измерена в почвенном газе (68 точек отбора проб) и в различных источниках воды (скважины и родники, 75 водозаборных точек, 66 родников, 9 скважин) с использованием радонового монитора AlphaGUARD PQ2000 PRO (Saphymo GmbH). Концентрация ^{222}Rn варьировалась от 0.12 до 73 Бк/л в воде и до 36.9 Бк·м$^{-3}$ в почвенном газе. Все места наблюдения были отмечены местоположением GPS. Данные прошли базовый статистический анализ и были визуализированы с помощью различных графиков. Впоследствии полевые данные были оцифрованы и интегрированы в ГИС-систему, которая выявила распределение ^{222}Rn в воде и почвенном газе на территории Квемо Картли.

Ключевые слова: картирование радона, почвенный газ, вода, ГИС, Квемо Картли, Грузия