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RADON-222 CONCENTRATION LEVELS IN SOIL AND WATER IN DIFFERENT REGIONS OF GEORGIA – RADON MAPPING

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Abstract. *Within the framework of the SRNSFG FN-19-22022 project "Radon mapping and radon risk assessment in Georgia", the authors carried out fieldwork to quantify the radon (^{222}Rn) distribution in water and soil gas as well as to ascertain geological factors influencing the radon concentration levels in some geographical areas of Georgia. On-site ^{222}Rn concentration has been measured in soil gas (more than 300 sampling points) and in various water sources (boreholes, wells, deep thermal wells and springs, over 500 samples) using AlphaGUARD PQ2000 PRO (Saphymo GmbH) radon monitor. The radon concentration ranged from 0.1 to 221 Bq/L in water and up to 80000 Bq/m³ in soil gas. All observation sites were marked by GPS position. The radon mapping, representing the key method for fulfilling the project requirements, is based on the application of geochemical methods. After processing, the field data were digitized and transferred into the GIS System, which revealed the connection of radon anomalies to geological and hydro-geological structures, including the tectonic faults.*

Keywords: *Rn mapping, soil gas, water, GIS, Georgia*

1. 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 radon concentrations in water and soil gas in different geographical areas of Georgia.

The works [1]-[5] present the results of our early studies of ^{222}Rn content in soil gas and water in various regions of the country.

2. METHODOLOGY OF MEASUREMENTS AND DATA CALCULATIONS

The field study was carried out by the mobile groups of researchers using an AlphaGUARD PQ 2000 PRO (hereafter "AlphaGUARD monitor") portable radon monitor based on the measurement principle of the pulse ionization chamber [6]. The instrument measures radon concentrations in air, soil gas as well as in water.

For water samples, the AquaKIT was used, 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 [8]. 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.

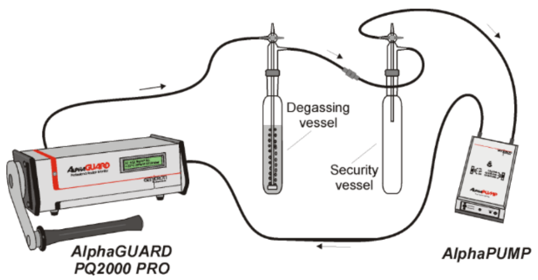

Figure 1. AquaKIT measurement set-up [8]

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]:

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

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 of 10-30 °C].

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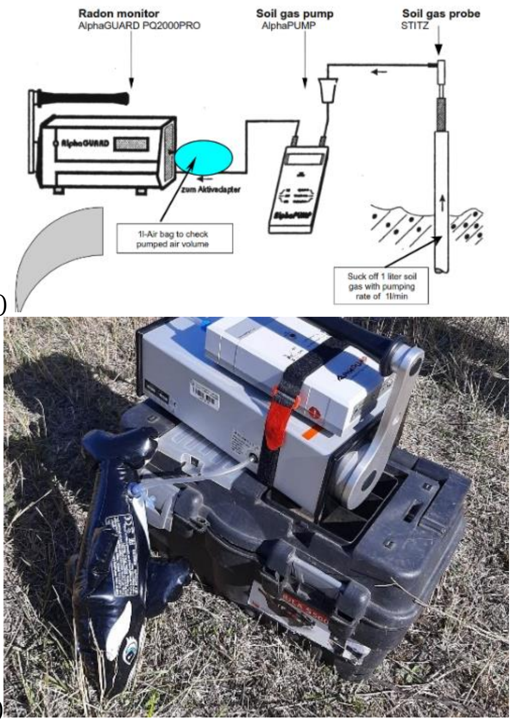
As a rule, the measurements followed the sampling with minimum delay. In case of delayed measurement, equation (2) was applied:

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

where, C_0 is the value at the moment of sampling, C is the measured value, $t_{1/2}$ is a half-life of ^{222}Rn, Δt is the time delay between sampling and measurement.

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 Radon progeny filter (Fig. 2a), following the user manual [9]. 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/m^3 was considered.



a)

b)

Figure 2. a) Soil gas measurement set-up [9], b) 1-litre balloon attached to the air outlet nozzle of the AlphaGUARD

The radon 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.

3. Results

The study area represents the component of the Caucasian segment of the Mediterranean (Alpine-Himalayan) collisional orogenic belt, which covers all major structural units of the Caucasian Orogeny: the Greater and the Lesser Caucasus fold systems and intermountain depressions lying between them. Lithology and geological structures of the region, the presence of many tectonic faults, radionuclides in rocks, various hydro-geological, geomorphological structures and soil characteristics determine the complexity of the territory. Based on all the above parameters, the relief maps of ^{222}Rn concentration in waters and soil in the entire territory were compiled using the GIS technique. Fig. 3 and Fig. 4 show the location of water and soil sampling points with the concentration range (size of the dots), respectively.

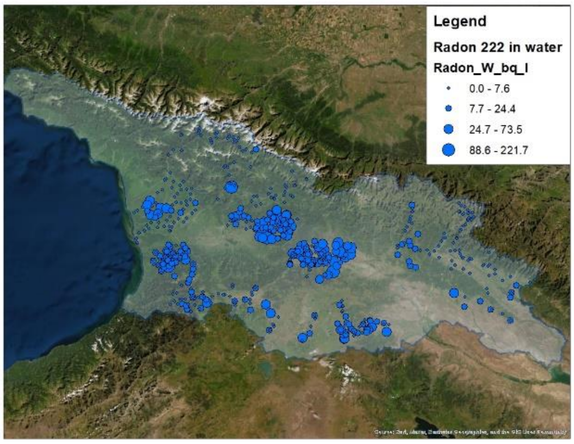


Figure 3. Water sampling points (blue dots) with ^{222}Rn concentration ranges (Bq/L) on the territory

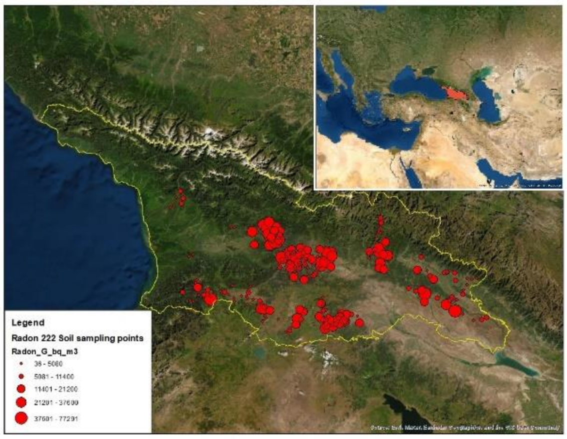


Figure 4. Soil sampling points (red dots) with ^{222}Rn concentration ranges (Bq/m^3) on the territory

The sampling locations are grouped into several regions in the next step and presented on geological maps using the GIS technique. Here also, the dot sizes represent ^{222}Rn concentration ranges for water (in blue) and soil gas (in red).

In the *Svaneti* and *Racha-Lechkhumi regions*, shown in Fig. 5, groundwater discharges mainly in the form of springs. In shallow groundwaters, the ^{222}Rn concentration is low, it varies between 0.8-4.6 Bq/L. In the mineral springs of deeper genesis, ^{222}Rn concentration grows up to 7-10.2 Bq/L (mineral springs Shavghele, Becho, etc.). As an exception, the spring with ^{222}Rn concentration of 104.7 Bq/L was found in the village Lesinidi in Lechkhumi. In the *Tusheri region*, the background ^{222}Rn concentration in springs is lower, between 0.5-5.1 Bq/L. Unfortunately, we do not have data on ^{222}Rn concentration in soil for the mentioned regions.

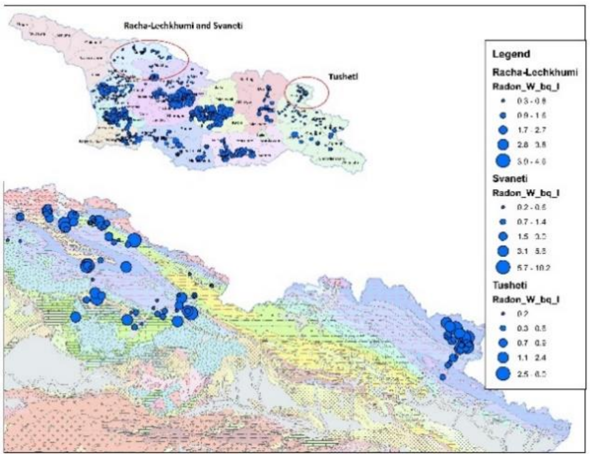
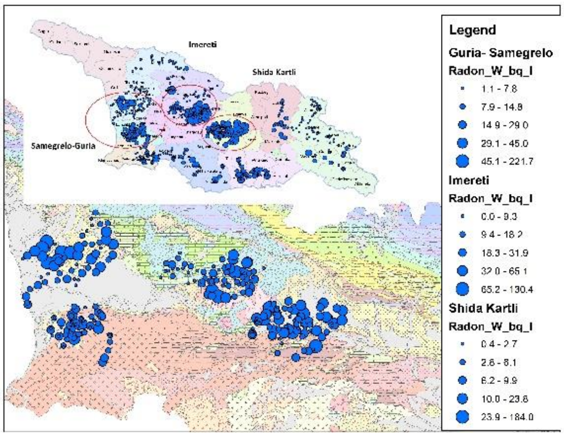


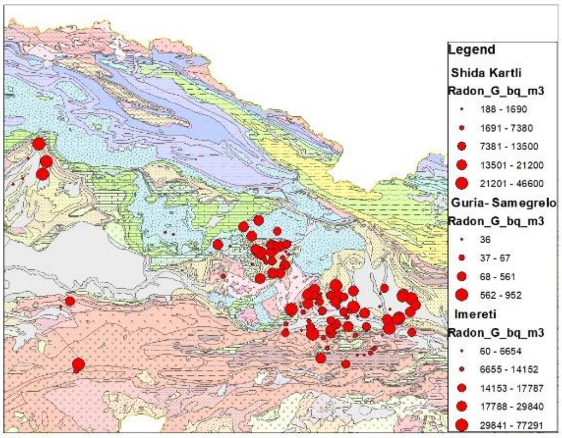
Figure 5. Water sampling points (blue dots) with ^{222}Rn concentration ranges (Bq/L) in Svaneti, Racha-Lechkhumi, Tusheti regions

Sampling was also conducted on the territory of the West part of the Georgian Plate, in particular in *Samegrelo, Guria, Imereti* and *Shida Kartli regions* (Fig. 6). In Samegrelo, springs are characterized by ^{222}Rn concentration up to 25 Bq/L, while varies between 0.2-55 Bq/L in waters from shallow wells. As to deep thermal wells, the observed value is in the range of 25-34 Bq/L (Tsaishi and Zugdidi). As to the Guria region, the background ^{222}Rn concentration in shallow groundwater varies between 2.9-10 Bq/L. In deep groundwater (sub-thermal) and mineral waters, ^{222}Rn concentrations are higher, mainly between 4.4-22.1 Bq/L. Several water sources with elevated ^{222}Rn concentration should be mentioned, such are two springs in Nasakiraly at 29 and 44.4 Bq/L, a spring in Atsana at 45 Bq/L, and the spring in Shemoqmedi with the highest value observed on the territory of Georgia at 221.7 Bq/L. As to ^{222}Rn concentration in soil gas, the average measured value is 7000 Bq/m^3. The low value can be related to the humid soil and the presence of low permeable clay layers close to the surface. There the Sedimentary rocks from the Quaternary age are developed here.

Elevated levels of ^{222}Rn in springs with high discharge rates characterize the territory of the Imereti region. The North part of the region (Sachkhere-Chiatura-Tkibuli) is represented by Lower Cretaceous age rocks, which contain fissure and fissure-karstic types of pressurized groundwater. The ^{222}Rn background value in the shallow groundwater varies between 1.9-12.7 Bq/L, while in groundwater of deeper genesis, the values increase to several dozens and reach 130.4 Bq/L in the spring in Marjvena Rkvia (Zestafoni municipality). The region also developed a deposit of low-radioactive thermal water, known as Tskaltubo resort, with a ^{222}Rn content of about 50-70 Bq/L. The content of radon in the water is low, which can be explained by the influence of near-surface groundwater circulation in this zone. As to soil gas content, it is also elevated in comparison to other regions of the country and, in some areas, reaches 77300 Bq/m^3. Here, the crystalline substrate (Dzirula uplift) is exposed in its central part, and the fault network between Adjara-Trialeti fold-thrust mountain belt and the Georgian Plate is developed. Shida Kartli region is characterized by low and moderate concentration values in the range of 0.1-18.4 Bq/L. The few springs with elevated radon concentrations of 28.4 - 51.8 Bq/L were also found. In the wells, with a depth of 22-190 m, observed values are between 3.0-25.6 Bq/L. In soil gas, ^{222}Rn concentration varies from few thousand to 10500-46600 Bq/m^3. Here are developed Sedimentary rocks of the Cretaceous-Quaternary age.



a)



b)

Figure 6. Sampling points of a) Water (blue dots) with ^{222}Rn concentration ranges (Bq/L) and b) Soil (red dots) with ^{222}Rn concentrations ranges (Bq/m^3) in the Guria-Samegrelo, Imereti and Shida Kartli regions

On the East part of the Georgian Plate was tested territory of the *Tianeti* and *Kakheti* (Fig. 7). In Tieneti, a low concentration of ^{222}Rn in water, about 0.1-11.6 Bq/L, was observed. Only in a few springs the value increases to 13.8-18.5 Bq/L. In Kakheti, in springs and sub-thermal wells, ^{222}Rn concentration is also low, 0.2-18.8 Bq/L. The highest value of 33.4 Bq/L was observed in the well (Tokhliauri). As to ^{222}Rn concentration in soil gas, the value is mainly few thousand; in some areas, it varies in the range of 10000-42126 Bq/m^3 and 10121-57700 Bq/m^3, correspondingly in Tianeti and Kakheti.

As to regions of *Adjara, Samtskhe-Javakheti* and *Qvemo Kartli* in South Georgia, the territory belongs to Adjara-Trialeti fold-thrust mountain belt and Javakheti plateau (highland). In all regions, the spring type of shallow groundwater dominates, where the ^{222}Rn concentration level is low, 0.6-13.6 Bq/L for Ajara, 0.87-12.2 Bq/L in Samtske-Javakheti and 0.4-15.6 Bq/L in Qvemo Kartli. In several mineral springs of deeper circulation, radon value increases to 18.5-32.0 Bq/L, 22.4-36.1 Bq/L and 21.8-73.5 Bq/L for Adjara and Samtskhe-Javakheti and Kvemo Kartli respectively (Fig. 8).

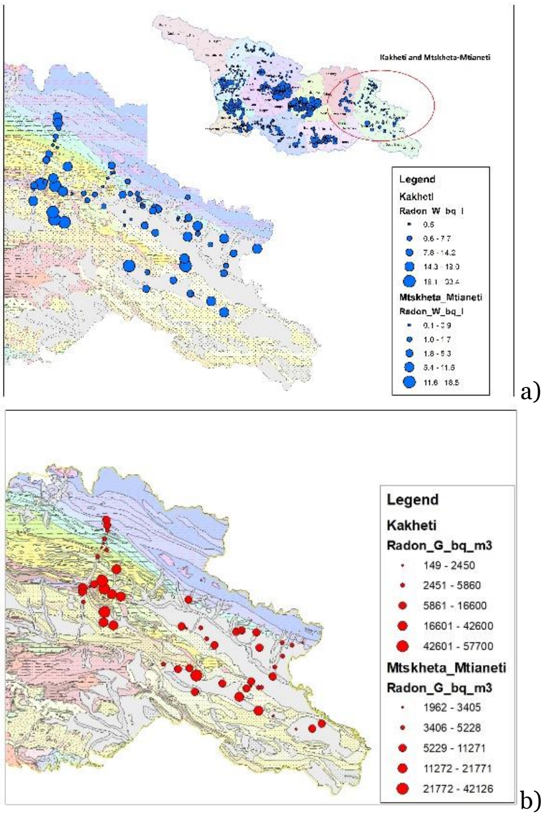


Figure 7. Sampling points of a) Water (blue dots) with ^{222}Rn concentration ranges (Bq/L) and b) Soil (red dots) with ^{222}Rn concentrations ranges (Bq/m^3) in the Kakheti and Mtskheta-Mtianeti regions

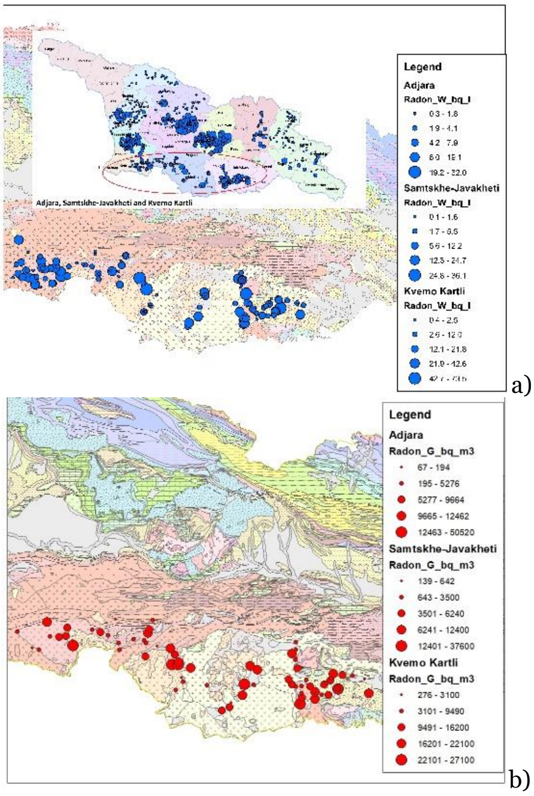


Figure 8. Sampling points of a) Water (blue dots) with ^{222}Rn concentration ranges (Bq/L) and b) Soil (red dots) with ^{222}Rn concentrations ranges (Bq/m^3) in the Adjara, Samtskhe-Javakheti and Kvemo Kartli regions

The volcanic and sedimental rocks of the Middle Eocene, with young lavas dacite-andesitic volcanic tuffs and basaltic-andesitic lava flows, are mainly developed on the mentioned territory. The ^{222}Rn concentration in soil gas varies within several thousand Bq/m^3. The maximum values observed are 50000, 37000 and 27100 Bq/m^3, correspondingly in Adjara, Samtskhe-Javakheti and Kvemo Kartli.

4. Conclusion

Peculiarities of distribution of radon concentration in selected surface, shallow and deep layer waters on some territories of Georgia were studied, such background and anomalous areas were outlined. The elevated radon concentration is related to the gas exhalation from deep layers, which are opened by the tectonic faults and hydro-geological "windows".

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