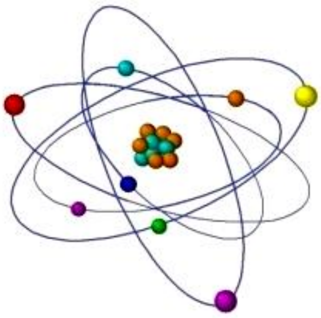
STATISTICAL ANALYSIS OF RADON CONCENTRATION IN THE GROUND LAYER OF AIR IN TBILISI



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ABSTRACT: *The results of statistical analysis of data on radon concentration in the ground layer of air in Tbilisi in 2010-2011 are presented. Radon concentrations were determined by measuring its nearest alpha decay products (radium A and radium C´). Air samples were collected into an AFA-RMP-20 filter for 5 minutes using a dedicated air pump. Alpha particles emitted from the filter were then counted using a BDZA receiver and a corresponding pulse counter. Measurements were taken four times daily: at 9:00, 12:00, 15:00, and 18:00 (at 17:00 in winter) at the third floor of the thermal chamber building (central Tbilisi, Kura River valley, a relatively unpolluted area, 8 meters above ground level, 41.754º N, 44.927º E, 450 m above sea level). Data analysis was performed without taking into account weather conditions.*

Statistical characteristics of hourly, average daily, and monthly radon concentrations (C) in different periods and seasons of the year are presented. The following were studied: linear correlation (R) between hourly and average daily radon concentrations in different seasons of the year; repetition of hourly and average daily values of radon concentrations; intra annual distribution of mean monthly radon concentration; linear correlation and regression between intra annual distribution of radon concentration in 2010 and 2011.

In particular, the following results were obtained. According to annual data, the average radon concentration varied from 3.2 Bq/m^3 at 17-18 h to 5.0 Bq/m^3 at 9 h, with a daily average of 3.8 Bq/m^3; the minimum C value was 0.4 Bq/m^3 at 9 h, and the maximum was 19.6 Bq/m^3, also at 9 h. The best correlations between hourly and average daily values of C are observed in winter ($0.73 \le R \le 0.95$), the worst – in summer ($0.08 \le R \le 0.82$). For different seasons of the year and measurement time radon concentration distributions have one maximum within the range of C values >2÷4 Bq/m^3 or>4÷6 Bq/m^3. The intra-annual distribution of mean monthly radon concentration (C^*) is J-shaped: a decrease in C^* values from January (first maximum value) to April-May (minimum), followed by an increase to maximum values in December. These distributions have the form of a fifth-degree polynomial. Coefficient of linear correlation between intra annual distribution of C^* values in 2010 and 2011 change from 0.89 *(for measurements at 9 hour) to 0.96 (for measurements at 12 hour). It is noted that the intra-annual distribution of C* values for the period under study was quite stable.*

Keywords: radon concentrations; direct and indirect radon risks; statistical analysis.

INTRODUCTION

Radon - 222 is a naturally occurring, colorless, and odorless radioactive gas produced by the radioactive decay of uranium and radium found in rock, soil, and groundwater. It is a major source of natural background radiation, typically found in low concentrations outdoors but accumulating in enclosed spaces, particularly basements and in radon-prone geological areas like granite [https://www.google.com/search?client=opera&q=radon+in+nature&sourceid=opera&ie=UTF-8&oe=UTF-8].

Radon is a unique trace element of the environment in many ways. Research into this gas has attracted scientists from many countries, including Georgia, for decades [1-7]. In particular, more than 65 years ago, B. Styra was the creator of the new direction of atmosphere physics – “nuclear meteorology”, that designates number of the problems of the study of the radioactivity of the atmosphere (including radon) in connection with the meteorological processes, proceeding in it. It notes that artificial radionuclides can be used also as the tracers for studying the motion of air masses [1,2,4].

Just four decades ago, it was believed that the role of this extremely rare, inert, radioactive chemical element in human life could not be significant, let alone noticeable (with the exception of personnel in mines, uranium pits, nuclear facilities, radon treatment facilities, etc.). Therefore, data on radon content in soil air and the atmosphere were (and still are) widely used in geology, prospecting geophysics, earthquake forecasting, atmospheric physics, and other fields, but not in ecology.

However, this has proven to be completely untrue. Radon accounts for approximately 50-55% of the radiation dose received annually by every person on Earth, and thoron adds another 5-10%. Moreover, in certain areas, radon exposure can be many times, or even orders of magnitude, higher than average. Therefore, problems of elevated radon levels are a concern for people in many countries today.

In this regard, the United States, Europe, Russia, and other countries are paying close attention to monitoring radon in soil, water, and residential buildings. Radon hazard mapping is underway, with subsequent consideration of relevant data in construction.

It has also been found that radon in the air, while posing no radiation risk, significantly influences the formation of so-called secondary aerosols in the atmosphere (sulfates, nitrates, etc.) via the gas-to-particle pathway. In other words, it indirectly impacts human health through increased aerosol particle levels, contributes to the formation of acid rain, and contributes to climate change (at least locally, within a large city and its surrounding areas) [1-9].

At the Institute of Geophysics, radon research in various aspects has been carried out since the mid-thirties of the last century and continues to this day (search for radioactive ores [10]; radioactivity of mineral springs [11]; radon research in the surface air layer [12-14], lower troposphere [15-19] and clouds [19,20]; use of radon as a tracer to determine the turbulence coefficient in the surface atmosphere [21,22] and lower troposphere [19,23,24]; assessment of radon exhalation in Georgia based on the results of aircraft soundings [25,26]; beginning of radon research in the human environment [27-29]; radon research in karst caves [30-34]; use of radon for medical purposes [33-35]; earthquake prediction [36-38]; radon research in soil and water [39-43], etc.). Particular attention was paid to the study of soil radon and its environmental consequences (small-scale preliminary mapping of the territory of Western Georgia for radon content in the soil was conducted, radon content in several hundred residential premises was studied, a link between radon content and lung cancer was established, etc.) [44,45], as well as monitoring radon in the atmosphere in terms of its influence on the formation of secondary aerosols in Tbilisi conditions [9,46-54].

In particular, the Tbilisi type of smog was identified for the first time, characterized by a feedback loop between radon content and the concentration of light ions in the air, which is impossible under natural conditions, caused by the formation of secondary aerosols in quantities capable, in combination with primary particles, of achieving, by attaching to themselves, a more intense decrease in ion content compared to their increase as a result of ionization. This effect, in conditions of a heavily polluted atmosphere, also applies to natural gamma and cosmic radiation [9,48-53].

This work is a continuation of previous studies. Below are some more detailed results of the analysis of 2010-2011 data on radon concentration in Tbilisi than was done previously [9].

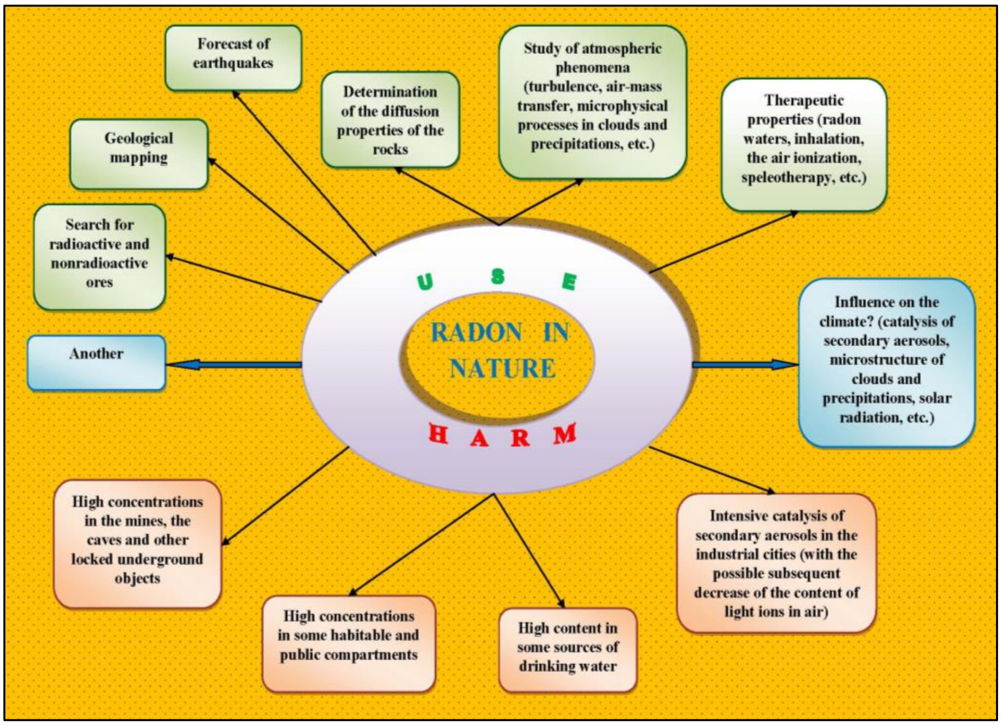

Fig.1 shows a sample flow chart of the beneficial role of radon in environmental studies, as well as the negative impact on the human environment

STUDY AREA, MATERIALS AND METHODS

Radon concentrations were determined by measuring its nearest alpha decay products (radium A and radium C´). Air samples were collected into an AFA-RMP-20 filter for 5 minutes using a dedicated air pump. Alpha particles emitted from the filter were then counted using a BDZA receiver and a corresponding pulse counter [9,55]. Measurements were taken four times daily: at 9:00, 12:00, 15:00, and 18:00 (at 17:00 in winter) at the third floor of the thermal chamber building (central Tbilisi, Kura River valley, a relatively unpolluted area, 8 meters above ground level, 41.754º N, 44.927º E, 450 m above sea level).

Data analysis was performed without taking into account weather conditions using standard statistical methods [56].

The following designations will be used below (besides those pointed out above and well-known): C_v - coefficient of variation (%); α - the level of significance; R – coefficient of linear correlation; R^2 - coefficient of determination; C - radon concentration, Bq/m^3. C(9), C(12), C(15), C(17-18) - radon concentration at the above measurement times; C(9-18) – daily mean radon concentration; h – hour. C^* (9), C^*(12), C^*(15), C^*(17-18), C^*(9-18) – monthly mean radon concentration at the above measurement times and period. Comparison of mean C values was carried out using the Student's t-test with a significance level of at least 0.25.

The degree of correlation according to [56]: very high correlation ($0.9 \le R \le 1.0$); high correlation ($0.7 \le R < 0.9$); moderate correlation ($0.5 \le R < 0.7$); low correlation ($0.3 \le R < 0.5$); negligible correlation ($0 \le R < 0.3$).

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RESULTS

The results in tables 1-3 and figs. 2 and 3a-7b are presented. Fig. 2 illustrates the time series of C values in the surface air layer of Tbilisi from January 1, 2010 to December 31, 2011. Table 1 presents the main statistical characteristics of C values for seven different seasons of the year (four observation periods and average daily values).

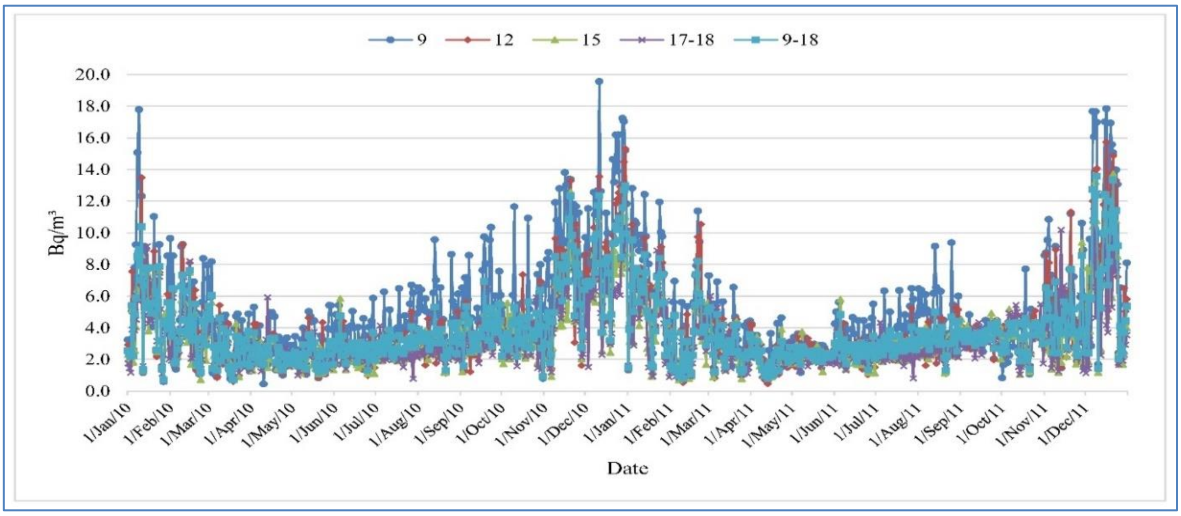

Fig. 2. Time series of hourly and average daily values of radon concentration in the ground layer of air in Tbilisi (in 2010 – 2011**).**

In particular, as can be seen from Table 1 and Fig. 2, radon concentration has both diurnal and seasonal variations. According to annual data, the average radon concentration varied from 3.2 Bq/m^3 at 17-18 h to 5.0 Bq/m^3 at 9 h, with a daily average of 3.8 Bq/m^3; the minimum C value was 0.4 Bq/m^3 at 9 h, and the maximum was 19.6 Bq/m^3, also at 9 h. The range of variability for C (9-18) values is 0.7-13.6 Bq/m^3.

Diurnal variations in average C values are observed for almost all the indicated seasons of the year, with a maximum at 9 h and a minimum at 15 h and 17-18 h in the warm and cold periods, in spring and summer, as well as at 17-18 h in winter and 15 h in autumn. In the seasonal variation of hourly average C values, the maximum is observed in winter, C(9) = 7.5 Bq/m^3, and the minimum is in spring, C(15) and C(17-18) = 2.2 Bq/m^3.

In the seasonal variation of daily average radon concentration values, the maximum is observed in winter, C(6-18) = 5.7 Bq/m^3, and the minimum is in spring, C(6-18) = 2.4 Bq/m^3.

The greatest variations in hourly radon concentrations are observed in winter (C_v varies from 57.3% at 17-18 h to 60.4% at 9 h), and the smallest in summer (C_v varies from 23.1% at 17-18 h to 35.7% at 9 h). For daily average radon concentration values, the variation coefficient varies from 22.7% in summer to 54.7% in winter.

In table 2 data on linear correlation coefficients between hourly and average daily values of radon concentrations in different seasons of the year are presented. As follows from table 2 values of R between study parameters make up. Year. The R values between hourly radon concentrations are in the range from 0.72 (high correlation) to 0.86 (high correlation). The R values between hourly and daily mean radon concentration are in the range from 0.88 (high correlation) to 0.95 (very high correlation).

Warm period. The correlation coefficients between hourly C values change from 0.34 (low correlation) to 0.64 (moderate correlation), and between hourly C and C(9-18) values change from 0.69 (moderate correlation) to 0.84 (high correlation). Cold period. The R values between hourly radon concentrations are in the range from 0.72 (high correlation) to 0.87 (high correlation). The R values between hourly and daily mean radon concentration are in the range from 0.88 (high correlation) to 0.95 (very high correlation). Winter.

The correlation coefficients between hourly C values change from 0.73 (high correlation) to 0.88 (high correlation), and between hourly C and C (9-18) values change from 0.88 (high correlation) to 0.95 (very high correlation). Spring. The R values between hourly radon concentrations are in the range from 0.48 (low correlation) to 0.72 (high correlation). The R values between hourly and daily mean radon concentration are in the range from 0.77 (high correlation) to 0.89 (high correlation). Summer. The correlation coefficients between hourly C values change from 0.08 (negligible correlation) to 0.50 (moderate correlation), and between hourly C and C(9-18) values change from 0.50 (moderate correlation) to 0.82 (high correlation). Autumn. The R values between hourly radon concentrations are in the range from 0.53 (moderate correlation) to 0.73 (high correlation). The R values between hourly and daily mean radon concentration are in the range from 0.81 (high correlation) to 0.91 (very high correlation).

Thus, the best correlations between the parameters under study are observed in winter, the worst – in summer.

In table 3 data on repetition of hourly and average daily values of radon concentrations in Tbilisi in 2010-2011 in different seasons of the year are presented.

Table 1. Statistical characteristics of hourly and average daily values of radon concentration in the ground layer of air in Tbilisi in 2010-2011 in different seasons of the year, Bq/m^3

Time, hour	**9**	**12**	**15**	**17-18**	**9 - 18**
Season	Year				
Mean	5.0	3.8	3.3	3.2	3.8
Min	0.4	0.5	0.7	0.6	0.7
Max	19.6	15.7	13.7	12.5	13.6
St Dev	3.3	2.6	1.9	1.9	2.3
C_v, %	66.6	67.4	59.4	58.7	59.0
Season	Warm half of the year, April – September, (Warm)				
Mean	3.7	2.7	2.5	2.5	2.9
Min	0.4	0.5	0.9	0.8	0.8
Max	10.3	6.7	5.8	6.4	6.9
St Dev	1.7	0.9	0.8	0.8	0.8
C_v, %	44.3	35.1	33.4	30.4	29.4
Season	Cold half of the year, October – March, (Cold)				
Mean	6.3	5.0	4.0	4.0	4.8
Min	0.6	0.5	0.7	0.6	0.7
Max	19.6	15.7	13.7	12.5	13.6
St Dev	4.0	3.1	2.4	2.3	2.8
C_v, %	64.4	62.7	59.7	59.0	57.3
Season	Winter				
Mean	7.5	6.1	4.8	4.6	5.7
Min	0.6	0.5	0.7	0.6	0.7
Max	19.6	15.7	13.7	12.5	13.6
St Dev	4.5	3.5	2.8	2.6	3.1
C_v, %	60.4	58.1	57.6	57.3	54.7
Season	Spring				
Mean	3.0	2.4	2.2	2.2	2.4
Min	0.4	0.5	0.7	0.7	0.7
Max	8.2	5.9	5.6	6.0	6.0
St Dev	1.4	1.0	0.8	0.9	0.9
C_v, %	47.3	43.2	37.5	39.3	35.9
Season	Summer				
Mean	4.2	2.8	2.5	2.5	3.0
Min	1.3	1.0	1.1	0.8	1.3
Max	9.6	5.3	5.8	4.3	5.3
St Dev	1.5	0.9	0.7	0.6	0.7
C_v, %	35.7	31.1	28.9	23.1	22.7
Season	Autumn				
Mean	5.4	4.2	3.6	3.7	4.2
Min	0.8	1.0	0.9	0.9	0.9
Max	13.8	13.3	12.6	12.0	12.3
St Dev	2.9	2.1	1.5	1.7	1.8
C_v, %	54.6	49.8	42.7	46.0	42.1

Table 2. Linear correlation coefficients between hourly and average daily values of radon concentrations in different seasons of the year

Time, hour	**9**	**12**	**15**	**17-18**	**9 - 18**
Season	Year				
9	1				
12	0.86	1			
15	0.78	0.86	1		
17-18	0.72	0.78	0.86	1	
9-18	0.93	0.95	0.93	0.88	1
Season	Warm				
9	1				
12	0.56	1			
15	0.46	0.63	1		
17-18	0.34	0.50	0.64	1	
9-18	0.84	0.82	0.80	0.69	1
Season	Cold				
9	1				
12	0.87	1			
15	0.79	0.86	1		
17-18	0.72	0.76	0.86	1	
9-18	0.94	0.95	0.93	0.88	1
Season	Winter				
9	1				
12	0.88	1			
15	0.83	0.87	1		
17-18	0.73	0.76	0.88	1	
9-18	0.94	0.95	0.95	0.88	1
Season	Spring				
9	1				
12	0.72	1			
15	0.61	0.71	1		
17-18	0.48	0.57	0.68	1	
9-18	0.87	0.89	0.86	0.77	1
Season	Summer				
9	1				
12	0.47	1			
15	0.38	0.47	1		
17-18	0.08	0.35	0.50	1	
9-18	0.82	0.78	0.73	0.50	1
Season	Autumn				
9	1				
12	0.72	1			
15	0.53	0.72	1		
17-18	0.54	0.66	0.73	1	
9-18	0.87	0.91	0.82	0.81	1

Table 3. Repetition of hourly and average daily values of radon concentrations in Tbilisi different seasons of the year, %

Season	Hour	Bq/m^3									
		0÷2	>2÷	>4÷	>6÷	>8÷1	>10÷1	>12÷1	>14÷1	>16÷1	>18÷2
Year	9	12.	35.9	26.6	9.5	6.7	4.1	2.3	0.7	1.6	0.1
	12	17.	50.1	16.8	7.3	4.2	1.8	1.5	0.7		
	15	22.	55.1	13.3	4.9	2.5	0.8	0.5			
	17-	23.	54.4	12.3	6.8	1.9	1.0	0.1			
	9-18	12.	58.1	15.9	7.1	4.0	1.6	1.2			
Warm	9	12.	50.0	27.6	7.4	2.2	0.3				
	12	20.	69.4	9.6	0.3						
	15	25.	69.4	5.2							
	17-	26.	70.8	3.0	0.3						
	9-18	12.	80.6	6.8	0.3						
Cold	9	12.	21.7	25.5	11.5	11.3	8.0	4.7	1.4	3.3	0.3
	12	14.	30.8	24.2	14.3	8.5	3.6	3.0	1.4		
	15	20.	40.7	21.4	9.9	4.9	1.6	1.1			
	17-	20.	37.9	21.7	13.5	3.8	1.9	0.3			
	9-18	11.	35.4	25.0	14.0	8.0	3.3	2.5			
Winter	9	11.	13.9	20.6	12.8	16.1	8.9	6.7	2.8	6.7	0.6
	12	12.	18.3	22.8	20.6	11.7	5.6	5.6	2.8		
	15	17.	27.8	24.4	16.7	8.3	3.3	1.7			
	17-	20.	27.8	21.7	20.6	7.2	2.2	0.6			
	9-18	12.	21.7	22.8	20.6	11.7	6.1	4.4			
Spring	9	27.	49.5	20.1	2.2	0.5					
	12	37.	52.7	10.3							
	15	42.	53.8	3.3							
	17-	44.	52.2	3.3	0.5						
	9-18	27.	67.4	4.9	0.5						
Summer	9	4.3	45.1	38.0	10.3	2.2					
	12	13.	76.6	9.8							
	15	21.	75.5	3.3							
	17-	19.	79.9	1.1							
	9-18	4.9	88.6	6.5							
Autumn	9	6.6	34.6	27.5	12.6	8.2	7.7	2.7			
	12	6.6	52.2	24.7	8.8	5.5	1.6	0.5			
	15	9.3	62.6	22.5	3.3	1.6	0.0	0.5			
	17-	10.	57.1	23.6	6.6	0.5	1.6				
	9-18	3.3	53.8	29.7	7.7	4.4	0.5	0.5			

As follows from this table, all radon concentration distributions have one maximum. Moreover, this maximum falls within the range of C values >2÷4 Bq/m^3 for all seasons of the year (from 27.8% for C(15) and C(17-18) in winter to 88.6% for C(17-18) in summer), except for the cold half of the year

(C(9)>4÷6 Bq/m^3, 25.5%) and winter (C(9), C(12) and C(9-18)>4÷6 Bq/m^3, repetitions of 20.6%, 22.8% and 22.8%, respectively).

In fig. 3a-7a graphs of intra annual distribution of monthly mean radon concentration in Tbilisi in 9, 12, 15, 17-18 and 9-18 hours in 2010 and 2011 are presented. These same figures show the regression equations for the corresponding distribution curves, which have the form of a fifth-degree polynomial ($R^2 \geq 0.9172$). In fig. 3b-7b graphs of linear correlation and regression between intra annual distribution of radon concentration in 2010 and 2011 in Tbilisi in 9, 12, 15, 17-18 and 9-18 hours 2011 are presented. The corresponding values of the regression coefficients are also presented here (R ≥ 0.89).

In general, all the above graphs of the intra-annual distribution of average monthly C values (figs. 3a-7a) have a J-shape: a decrease of C* values from January (the first highest value) to April-May (minimum), followed by an increase to maximum values in December.

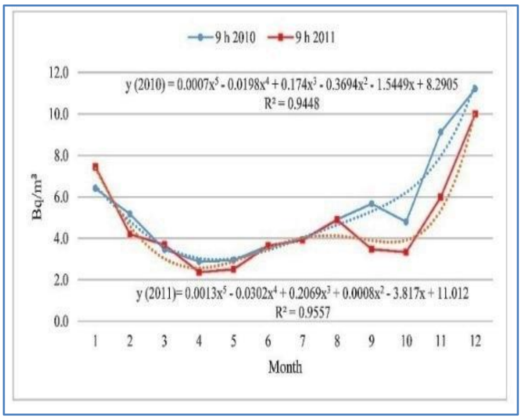

Fig. 3a. Intra annual distribution of radon concentration in Tbilisi in 9 h in 2010 and 2011.

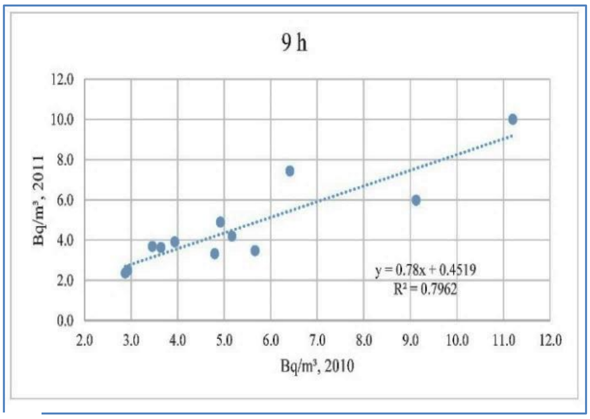

Fig. 3b. Linear correlation and regression between intra annual distribution of radon concentration in 2010 and 2011 in Tbilisi in 9 h. R=0.89 (high correlation).

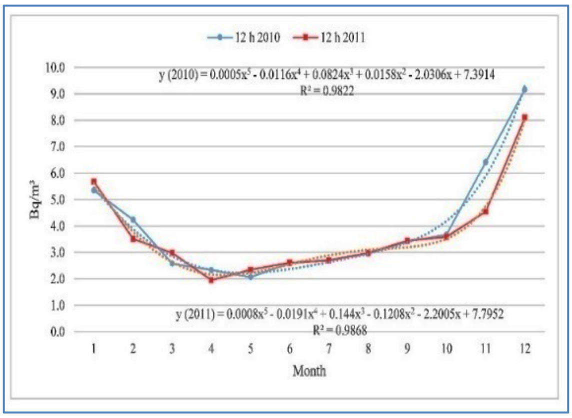

Fig. 4a. Intra annual distribution of radon concentration in Tbilisi in 12 h in 2010 and 2011.

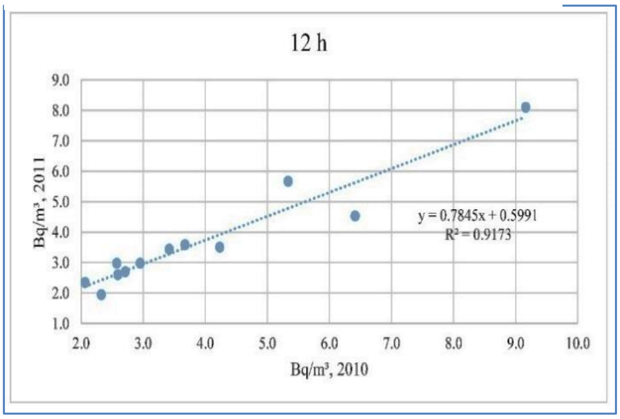

Fig. 4b. Linear correlation and regression between intra annual distribution of radon concentration in 2010 and 2011 in Tbilisi in 12 h. R=0.96 (very high correlation).

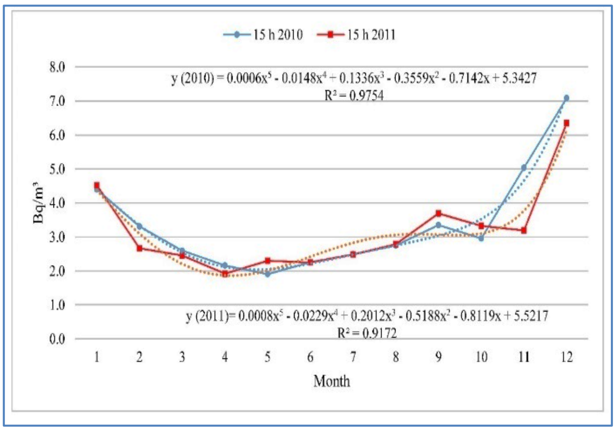

Fig. 5a. Intra annual distribution of radon concentration in Tbilisi in 15 h in 2010 and 2011.

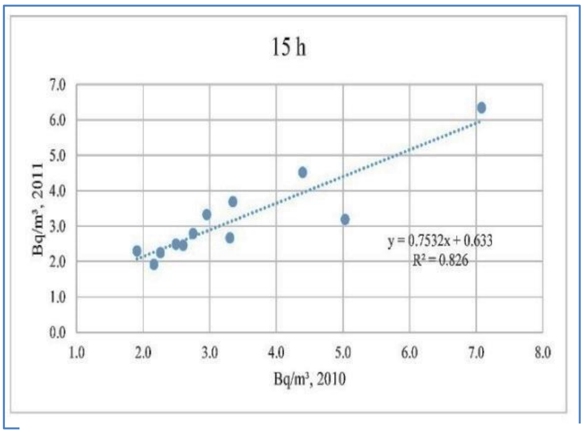

Fig. 5b. Linear correlation and regression between intra annual distribution of radon concentration in Tbilisi in 15 h. R=0.91 (very high correlation).

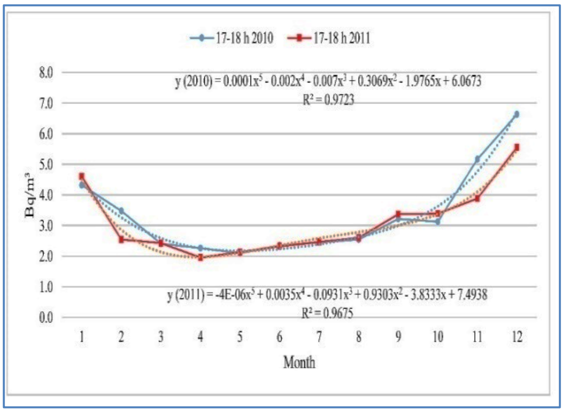

Fig. 6a. Intra annual distribution of radon concentration in Tbilisi in 17-18 h

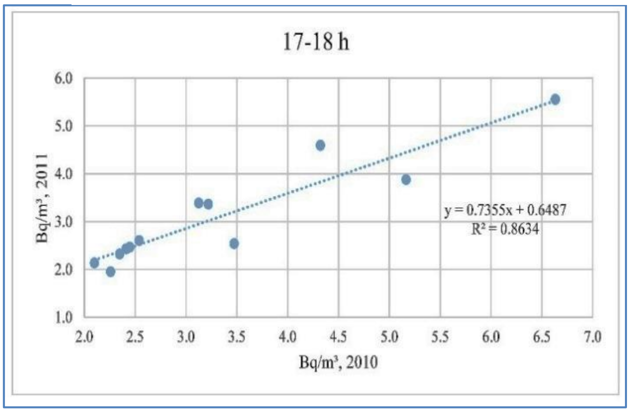

Fig. 6b. Linear correlation and regression between intra annual distribution of radon concentration in Tbilisi in 17-18 h. R=0.93 (very high correlation).

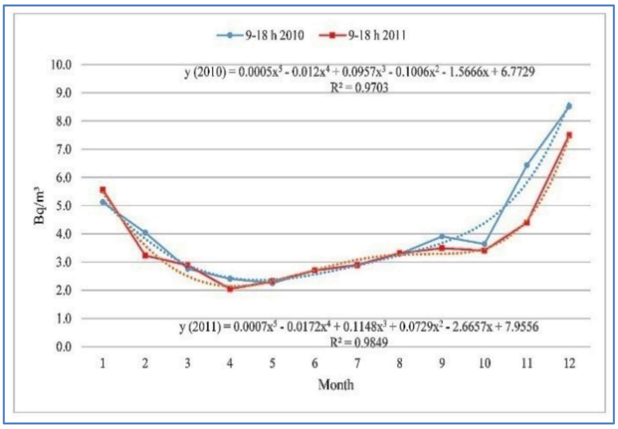

Fig. 7a. Intra annual distribution of daily mean radon concentration in Tbilisi

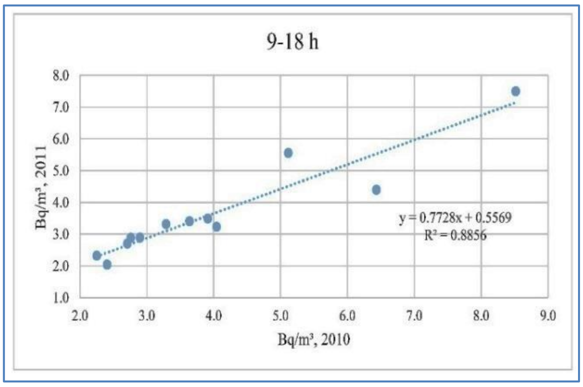

Fig. 7b. Linear correlation and regression between intra annual distribution of daily mean radon concentration in Tbilisi. R=0.94 (very high correlation).

The corresponding extreme C values are as follows:

- $C^*(9)$. 2010: 6.4, 2.9 (April), and 11.2 Bq/m3; 2011: 7.4, 2.4 (April), and 10.0 Bq/m^3.
- $C^*(12)$. 2010: 5.3, 2.1 (May), and 9.2 Bq/m3; 2011: 5.7, 1.9 (April), and 8.1 Bq/m^3.
- $C^*(15)$. 2010: 4.4, 1.9 (May) and 7.1 Bq/m3; 2011: 4.5, 1.9 (April) and 6.3 Bq/m^3.
- $C^*(17\text{-}18)$. 2010: 4.3, 2.1 (May) and 6.6 Bq/m3; 2011: 4.6, 2.0 (April) and 5.6 Bq/m^3.
- $C^*(9\text{-}18)$. 2010: 5.1, 2.2 (May) and 8.5 Bq/m3; 2011: 5.6, 2.0 (April) and 7.5 Bq/m^3.

It should be noted that the intra-annual distribution of monthly average C values during the study period was quite stable. A significant increase in 2011 compared to 2010 was observed for only 5 out of 60-time measurement cases in the range from 0.3 Bq/m^3 (May, $C^*(12)$) to 0.4 Bq/m^3 (March, $C^*(12)$); a decrease was observed for 22 cases in the range from -0.2 Bq/m^3 (April, $C^*(15)$) to -3.1 Bq/m^3 (November, $C^*(9)$).

In January, June, July, and August, all C^* values in 2010 and 2011 did not differ significantly from each other. Insignificant differences between the indicated C^* values in other months for different measurement times are as follows: March - $C^*(9)$, $C^*(15)$, $C^*(17\text{-}18)$, $C^*(9\text{-}18)$; May - $C^*(17\text{-}18)$, $C^*(9\text{-}18)$; September - $C^*(12)$, $C^*(17\text{-}18)$; October - $C^*(12)$, $C^*(17\text{-}18)$, $C^*(9\text{-}18)$; December - $C^*(12)$, $C^*(15)$.

Finally, we also note that the presence of stability in the intra-annual distribution of average monthly values of C is also indicated by the high level of correlation between these distributions in 2010 and 2011 (Fig. 3b-7b). The value of the linear correlation coefficient between these distributions varies from 0.89 (high correlation, $C^*(9)$) to 0.96 (very high correlation, $C^*(12)$).

CONCLUSION

In the future, we plan to conduct a similar study taking into account meteorological factors.

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