

# SOME RESULTS OF THE STUDY OF THE NUMBER OF DAYS WITH FOG PER YEAR IN GEORGIA IN 1993-2022

Nino Jamrishvili<sup>1</sup>, Mikheil Pipia<sup>1,2</sup>, Nazibrola Beglarashvili<sup>2,3</sup>,  
Nana Berdzenishvili<sup>4</sup>, Liana Kartvelishvili<sup>2,5</sup>

<sup>1</sup>M. Nodia Institute of Geophysics of Ivane Javakishvili Tbilisi State University, GEORGIA

<sup>2</sup>Institute of Hydrometeorology of Georgian Technical University, Tbilisi, GEORGIA

<sup>3</sup>Samtskhe-Javakheti State University, Akhaltsikhe, GEORGIA

<sup>4</sup>Iakob Gogebashvili Telavi State University, Telavi, GEORGIA

<sup>5</sup>National Environmental Agency, Tbilisi, GEORGIA

[n.jamrishvili76@gmail.com](mailto:n.jamrishvili76@gmail.com)

[m.pipia@gtu.ge](mailto:m.pipia@gtu.ge)

[beglarashvilinani@yahoo.com](mailto:beglarashvilinani@yahoo.com)

[nanaka.berdzenishvili@yahoo.com](mailto:nanaka.berdzenishvili@yahoo.com)

[lianakartvelishvili@yahoo.com](mailto:lianakartvelishvili@yahoo.com)

## Abstract

*Fog poses a serious threat to many sectors of the economy, particularly aviation and other types of transport. In this context, many countries around the world are giving great importance to fog research, especially in light of climate change. In Georgia, such research has also been a priority for many decades. This paper presents the results of a statistical analysis of data on the number of foggy days per year at 40 meteorological stations in Georgia (18 and 22 stations in eastern and western Georgia, respectively) between 1993 and 2022. The altitude range of the Eastern Georgian stations is from 362 to 1,744 metres above sea level (m a.s.l.), and the range for the Western Georgian stations is from 2 to 2,025 m a.s.l. In particular, it was found that the average number of days with fog per year at one meteorological station in Eastern Georgia is 22 (with a range of 0 to 111 across individual years), and 48 in Western Georgia (with a range of 0 to 325). There is a linear connection between the maximum and minimum number of days with fog and the average number of days with fog. In both eastern and western Georgia, an increasing linear trend in the average and maximum number of foggy days with altitude is observed. The variability of the number of foggy days at twelve stations with continuous thirty-year time series was studied. It was found that, compared to 1993-2007, a significant increase in the number of foggy days was observed at four stations between 2008 and 2022, while a decrease was observed at only one station. Trends in the number of foggy days per year for some stations were studied for the period 1993–2022. Thus, the trends for Akhalkalaki and Khashuri are linear, while the trend for Mta-Sabueti is a second-degree polynomial.*

**Keywords:** fog, number of days with fog per year, climate change, statistical analysis, trend

## I. Introduction

Fog has a significant impact on the environment, global and regional climate, heat and radiation balance of the atmosphere, air quality, water, flora and fauna, air-surface interaction, etc. [1-5]. Fog poses a serious threat to many sectors of the economy, including all types of transport, especially aviation [6-8]. Therefore, fog research is given great importance in many countries of the world, especially given climate change. In Georgia, such research is also considered a priority and has been carried out for many decades [1, 2, 5-7, 9-14].

For example, a detailed analysis of the variability of the number of fog days per year and some reasons of these variations in different locations of Georgia is given in [9-12]. In [13] the detailed statistical analysis of number of days with the fog, duration of fogs, number of days with the haze and duration of haze in Dusheti (Georgia) in 1941-1990 are present. As a whole in these years there was a tendency of the decrease of the number of days with the fogs and duration of fogs, and increase in the number of days with the haze and the duration of haze. In [6,7] the results of the study of fog characteristics at the Tbilisi airport are presented.

Obtaining new information allows for regular updates of the climatology and variability of the number of foggy days per year in different regions of Georgia, taking into account local conditions and climate change. The results of these studies based on observations at 40 stations from 1993 to 2022 are presented below.

## II. Study area, material and methods

Study area – Georgia, 40 meteorological stations (Table 1); 18 and 22 stations locations in Eastern and Western Georgia, respectively. The altitude range of meteorological stations in Eastern Georgia is from 362 to 1744 m a.s.l., and in Western Georgia - from 2 to 2025 m a.s.l.

**Table 1:** Coordinates and altitudes above sea level of weather stations.

Location	Lat, °N	Lon, °E	Height a.s.l., m	Location	Lat, °N	Lon, °E	Height a.s.l., m
Eastern Georgia				Akhalkalaki	41.42	43.48	1716
Akhalgori	42.12	44.48	760	Akhaltzikhe	41.63	43	982
Bolnisi	41.45	44.55	534	Bakmaro	41.85	42.32	1926
Dedoplistskaro	41.47	46.08	800	Bakuriani	41.73	43.52	1665
Dusheti	42.30	44.87	920	Batumi	41.65	41.63	2
Gori	41.98	44.12	588	Chakvi	41.73	41.73	30
Gurjaani	41.75	45.8	410	Chokhatauri	42.02	42.26	150
Khashuri	42	43.57	709	Goderdzi	41.63	42.52	2025
Kojori	41.67	44.70	1381	Khulo1	41.65	42.32	914
Kvareli	41.97	45.83	449	Khulo2	41.65	42.30	1338
Lagodekhi	41.82	46.3	362	Kobuleti	41.76	41.78	7
Sagarejo	41.73	45.33	802	Kutaisi	42.27	42.6	114
Shovi	42.7	43.68	1507	Lanchkhuti	42.10	42.03	10
Stepantsminda	42.67	44.65	1744	Mta-Sabueti	42.03	43.48	1242
Tbilisi	41.72	44.8	403	Poti	42.13	41.7	4
Tbilisi,Airport	41.68	44.95	462	Sachkhere	42.35	43.42	415
Tbilisi,Varketili	41.75	44.77	432	Sairme	41.9	42.75	910
Telavi	41.93	45.48	568	Senaki	42.20	41.95	6
Tsalka	41.6	44.08	1457	Torsa	42.39	41.79	14
Western Georgia				Tseva	42.08	43.13	508
Abastumani	41.75	42.83	1265	Zugdidi	42.52	41.88	117

Data of the Georgian National Environment Agency about number of days with fog per year in the period from 1993 to 2022 are used. The analysis of data is carried out with the use of the standard statistical analysis methods of random events and methods of mathematical statistics for the non-accidental time series of observations [15, 16]. The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; St Dev - standard deviation;  $\sigma_m$  – standard error;  $R^2$  - coefficient of determination; R – coefficient of linear correlation;  $C_v$  – coefficient of variation, %;  $K_{DW}$  – Durbin-Watson statistic;  $\alpha$  - level of significance; 95%(+/-) and 99%(+/-) - confidence intervals of average value; N- number of days with fog per year; H - elevation of terrain, meter a.s.l. Comparison of mean values of N in two 15 - year periods of time

(1993-2007 and 2008-2022) was produced with the use of Student's criterion with the level of significance  $\alpha$  not worse than 0.25. The degree of correlation was determined in accordance with [16]: very high correlation ( $0.9 \leq R \leq 1.0$ ); high correlation ( $0.7 \leq R < 0.9$ ); moderate correlation ( $0.5 \leq R < 0.7$ ); low correlation ( $0.3 \leq R < 0.5$ ); negligible correlation ( $0 \leq R < 0.3$ ). The curve of trend is equation of the regression of the connection of the investigated parameter with the time at the significant value of the determination coefficient and such values of  $K_{DW}$ , where the residual values are accidental.

### III. Results

Results in Table 2-4 and Fig. 1-9 are presented.

In Tables 2 and 3 statistical characteristics of the number of days with fog per year in Eastern and Western Georgia in 1993-2022 are presented. In Fig. 1 and 2 for clarity maps of distribution of the average and maximum number of days with fog per year on the territory of Georgia in 1993-2022 are presented.

As follows from Table 2, in Eastern Georgia the range of changes in the average values of N for each station is: 3 (Akhalgori) – 73 (Kojori), minimal: 0 (Akhalgori; Kojori; Tbilisi, Varketili) – 22 (Sagarejo), maximum: 11 (Akhalgori) – 111 (Kojori). The averaged at one meteorological station number of days with fog per year is 22. The range of changes values of  $C_v$  is: 31.2 % (Dedoplistskaro) – 164.4 % (Tbilisi).

**Table 2:** Statistical characteristics of the number of days with fog per year in Eastern Georgia in 1993-2022.

Location	Mean	Min	Max	St Dev	$\sigma_m$	$C_v, \%$	Count	95%(+/-)	99%(+/-)
Akhalgori	3	0	11	3.3	1.0	103.6	13	1.9	2.5
Bolnisi	25	11	39	8.0	1.5	31.8	30	2.9	3.8
Dedoplistskaro	53	12	85	16.7	4.6	31.2	14	9.1	11.9
Dusheti	29	3	68	17.8	5.1	60.6	13	10.1	13.2
Gori	11	4	29	5.3	1.0	49.9	30	1.9	2.5
Gurjaani	7	1	20	4.7	1.3	64.7	14	2.6	3.4
Khashuri	10	1	25	5.8	1.1	57.6	30	2.1	2.8
Kojori	73	0	111	30.5	8.5	41.8	14	16.6	21.8
Kvareli	6	1	12	3.0	0.9	48.7	13	1.7	2.3
Lagodekhi	10	2	33	7.9	2.2	76.0	14	4.3	5.6
Sagarejo	45	22	78	16.7	4.6	37.3	14	9.1	12.0
Shovi	32	2	66	18.4	3.8	58.4	24	7.5	9.9
Stepantsminda	31	3	67	19.9	5.5	63.8	14	10.8	14.2
Tbilisi	13	1	71	20.6	4.0	164.4	27	7.9	10.4
Tbilisi,Airport	19	3	31	8.8	2.1	46.0	18	4.2	5.5
Tbilisi,Varketili	9	0	36	11.0	3.0	121.2	14	6.0	7.9
Telavi	10	1	24	6.1	1.1	61.3	30	2.2	2.9
Tsalka	13	2	30	7.1	1.3	53.4	30	2.6	3.4

In Western Georgia (Table 3) the range of changes in the average values of N for each station is: 3 (Akhalkalaki) – 282 (Mta-Sabueti), minimal: 0 (Abastumani, Akhalkalaki, Bakuriani, Batumi, Chokhatauri, Kobuleti, Senaki, Zugdidi) – 248 (Mta-Sabueti), maximum: 11 (Zugdidi) – 325 (Mta-Sabueti). The averaged at one meteorological station number of days with fog per year is 48. The range of changes values of  $C_v$  is: 6.9 % (Mta-Sabueti) – 171.8 % (Kutaisi).

**Table 3:** Statistical characteristics of the number of days with fog per year in Western Georgia in 1993-2022.

Location	Mean	Min	Max	St Dev	$\sigma_m$	$C_v, \%$	Count	95%(+/-)	99%(+/-)
Abastumani	5	0	20	6.1	1.8	112.5	13	3.5	4.6
Akhalkalaki	3	0	12	3.1	0.6	88.9	30	1.1	1.5
Akhaltzikhe	9	2	22	4.4	0.8	52.3	30	1.6	2.1
Bakhmaro	69	42	106	18.9	5.7	27.4	12	11.1	14.6
Bakuriani	36	0	99	28.0	6.6	78.7	19	12.9	17.0
Batumi	5	0	21	5.1	1.3	109.5	16	2.6	3.4
Chakvi	6	1	17	4.5	1.3	82.0	13	2.6	3.4
Chokhatauri	8	0	69	13.8	2.6	163.6	30	5.0	6.6
Goderdzi	197	154	219	17.6	4.9	8.9	14	9.5	12.5
Khulo1	27	2	66	14.4	3.7	53.5	16	7.3	9.6
Khulo2	130	68	181	29.8	8.3	23.0	14	16.2	21.3
Kobuleti	12	0	34	7.6	1.4	61.3	30	2.8	3.7
Kutaisi	7	1	72	12.5	2.3	171.8	30	4.5	6.0
Lanchkhuti	16	5	35	10.4	3.0	65.5	13	5.9	7.8
Mta-Sabueti	282	248	325	19.4	3.6	6.9	30	7.1	9.3
Poti	23	13	49	8.8	2.0	38.3	20	3.9	5.2
Sachkhere	14	2	24	7.0	2.1	49.0	12	4.1	5.4
Sairme	133	14	261	70.9	18.3	53.3	16	35.9	47.2
Senaki	7	0	18	5.6	1.6	85.8	13	3.2	4.2
Torsa	14	1	56	15.5	4.5	114.6	13	8.8	11.5
Tseva	46	21	68	14.3	4.1	30.8	13	8.1	10.6
Zugdidi	4	0	11	2.7	0.6	72.8	22	1.1	1.5

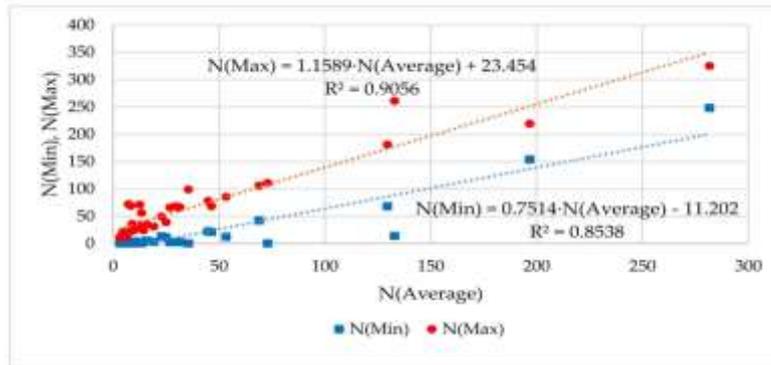


**Figure 1:** Distribution of the average number of days with fog per year on the territory of Georgia in 1993-2022.



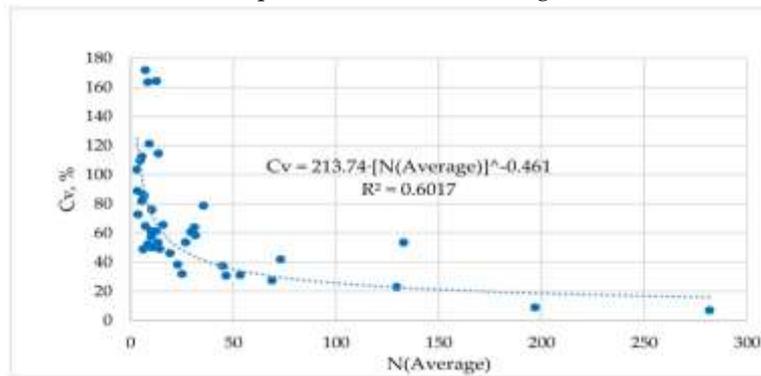
**Figure 2:** Distribution of the maximum number of days with fog per year on the territory of Georgia in 1993-2022.

Fig. 3 shows the graphs of the correlations between the maximum and minimum number of foggy days per year with their average values.



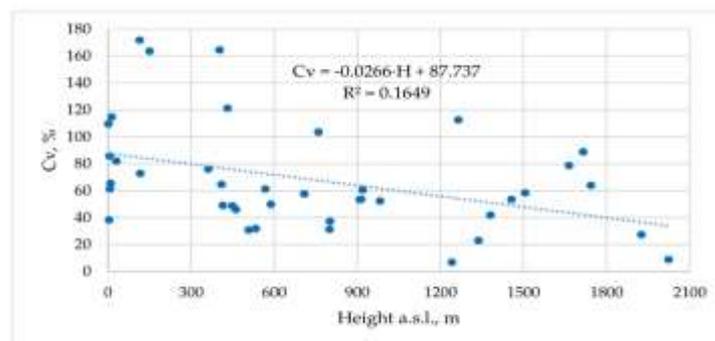
**Figure 3:** Linear correlation and regression the maximum and minimum number of days with fog per year with average number of days with fog per year in Georgia in 1993-2022.

As follows from Fig. 3 degree of these correlations were very high: for pair N(Min) – N(Average) value of R is 0.92 and for pair N(Max) – N(Average) value of R is 0.95.



**Figure 4:** Connection of coefficient of variation with the average number of days with fog per year in Georgia in 1993-2022.

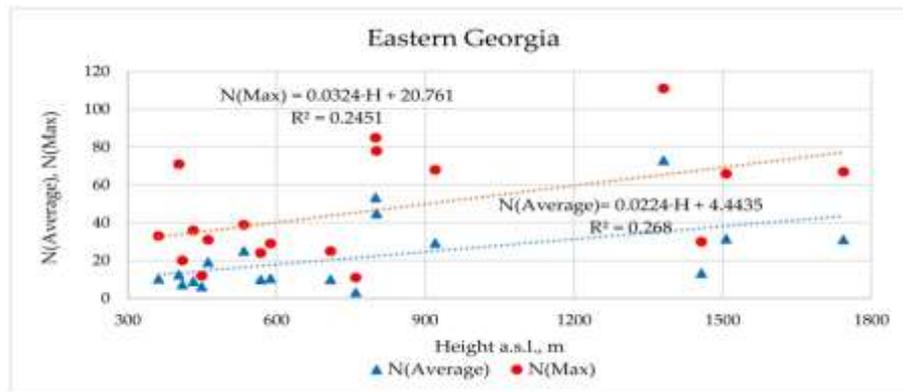
Connection of coefficient of variation with the average number of days with fog per year has a power form (Fig. 4). With the increase in the values of N(Average), a significant decrease in the values of Cv is observed.



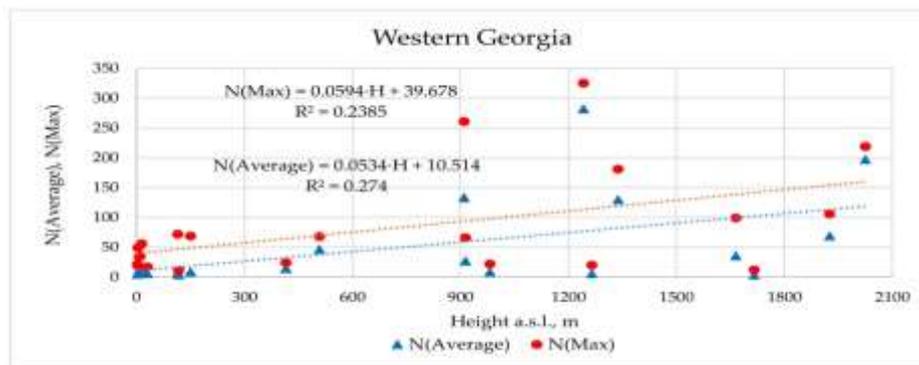
**Figure 5:** Connection of coefficient of variation of the number of days with fog per year with the height on the territory of Georgia in 1993-2022.

The relationship between the coefficient of variation of the number of days with fog per year and the altitude of the terrain in Georgia has the form of an inverse linear relationship (Fig. 5). For pair  $C_v - H$  value of  $R$  is 0.41 (low correlation).

In Fig. 6 and 7 vertical distributions of the maximum and average number of days with fog per year on the territory of Eastern and Western Georgia are presented. For all cases, there are tendencies towards increasing values  $N(\text{Average})$  and  $N(\text{Max})$  with the altitude of the place. For Eastern Georgia (Fig. 5) for pair  $N(\text{Average}) - H$  value of  $R$  is 0.52 (moderate correlation) and for pair  $N(\text{Max}) - H$  value of  $R$  is 0.50 (moderate correlation).



**Figure 6:** Vertical distribution of the maximum and average number of days with fog per year on the territory of Eastern Georgia in 1993-2022.



**Figure 7:** Vertical distribution of the maximum and average number of days with fog per year on the territory of Western Georgia in 1993-2022.

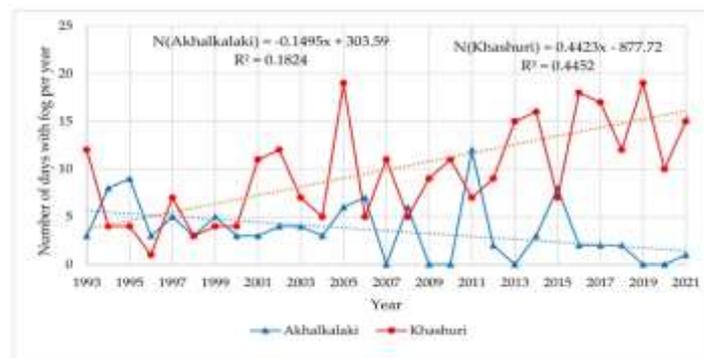
For Western Georgia (Fig. 7) for pair  $N(\text{Average}) - H$  value of  $R$  is 0.52 (moderate correlation) and for pair  $N(\text{Max}) - H$  value of  $R$  is 0.49 (low correlation).

In Table 4 data on difference between of the average number of days with fog per year in 2008-2022 and 1993-2007 for 12 locations with a continuous thirty-year time-series of observations are presented. As follows from Table 4 in 2008-2022, compared to 1993-2007, a significant increase in the number of days with fog was observed at four stations (Chokhatauri, Khashuri, Mta-Sabueti, Tbilisi), and a decrease at only one (Akhalkalaki).

Finally, in Fig. 8 and 9 examples of trends of the number of fog days per year for Akhalkalaki, Khashuri and Mta-Sabueti in 1993-2022 are given.

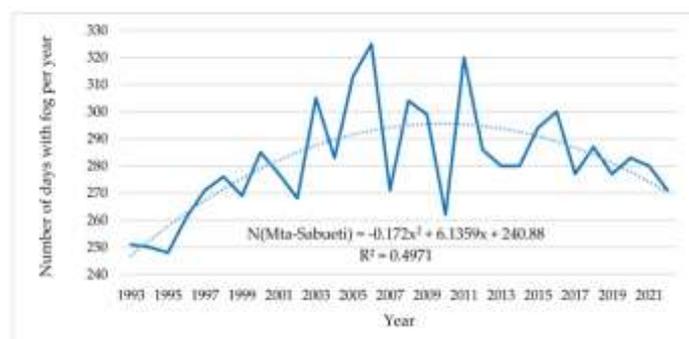
**Table 4:** Difference between of the average number of days with fog per year in 2008-2022 and 1993-2007 for 12 locations of Georgia.

Location	1 per.(1993-2007)	2 per.(2008-2022)	2 per.-1 per.	$\alpha$
Akhalkalaki	4.4	2.5	-1.9	$\leq 0.25$
Akhaltsikhe	9.2	7.8	-1.4	$> 0.25$
Bolnisi	26.0	24.1	-1.9	$> 0.25$
Chokhatauri	2.8	14.1	11.3	$\leq 0.25$
Gori	10.4	10.7	0.3	$> 0.25$
Khashuri	7.3	13.0	5.7	$\leq 0.25$
Kobuleti	11.0	13.9	2.9	$> 0.25$
Kutaisi	10.3	4.3	-6.0	$> 0.25$
Mta-Sabueti	276.9	286.7	9.8	$\leq 0.25$
Tbilisi	6.2	17.7	11.5	$\leq 0.25$
Telavi	9.5	10.5	1.1	$> 0.25$
Tsalka	14.8	11.9	-2.9	$> 0.25$



**Figure 8:** Trend of the number of days with fog per year in Akhalkalaki and Khashuri in 1993-2022.

Trends of the number of days with fog per year in Akhalkalaki and Khashuri have a linear form (Fig. 8). Akhalkalaki ( $K_{DW} = 2.37$ ,  $\alpha = 0.05$ ); Khashuri ( $K_{DW} = 2.23$ ,  $\alpha = 0.05$ ).



**Figure 9:** Trend of the number of days with fog per year in Mta-Sabueti in 1993-2022.

Trend of the number of days with fog per year in Mta-Sabueti (Fig. 9) have form of a second-degree polynomial ( $K_{DW} = 2.64$ ,  $\alpha = 0.01$ ).

#### IV. Conclusion

In Eastern Georgia the range of changes in the average values of number of days with fog per year (N) for each station is: 3 (Akhlagori) – 73 (Kojori), minimal: 0 (Akhlagori; Kojori; Tbilisi, Varketili) – 22 (Sagarejo), maximum: 11 (Akhlagori) – 111 (Kojori). The averaged at one meteorological station number of days with fog per year is 22. In Western Georgia the range of changes in the average values of N for each station is: 3 (Akhalkalaki) – 282 (Mta-Sabueti), minimal: 0 (Abastumani, Akhalkalaki, Bakuriani, Batumi, Chokhatauri, Kobuleti, Senaki, Zugdidi) – 248 (Mta-Sabueti), maximum: 11 (Zugdidi) – 325 (Mta-Sabueti). The averaged at one meteorological station number of days with fog per year is 48.

Vertical distributions of the maximum and average number of days with fog per year on the territory of Eastern and Western Georgia tends to increase with increasing altitude.

A difference between of the average number of days with fog per year in 2008-2022 and 1993-2007 for 12 locations with a continuous thirty-year time-series of observations are studied. In 2008-2022, compared to 1993-2007, a significant increase in the number of days with fog was observed at four stations (Chokhatauri, Khashuri, Mta-Sabueti, Tbilisi), and a decrease at only one (Akhalkalaki). Trends of the N in Akhalkalaki and Khashuri have a linear form, and in Mta-Sabueti - form of a second-degree polynomial

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#### CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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