Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 28(2), 2025, pp. 44-56

Statistical Analysis of the Total Number of Dry Months in Eastern Georgia in 1936-2023 Using the SPI-3 Index ≤ 0 and an Assessment of the Variability of this Number until 2045

[1]Avtandil G. Amiranashvili, [2]Teimuraz P. Davitashvili, [1]Oleg A. Kharshiladze, [3]Inga G. Samkharadze, [1]Dimitri Z. Amilakhvari

[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Georgia
[2]Ilia Vekua Institute of Applied Mathematics of Ivane Javakhishvili Tbilisi State University, Georgia
[3] Hydrometeorological Institute of Georgian Technical University, Georgia

ABSTRACT

A detailed statistical analysis of the total number of dry months (N) in Eastern Georgia in 1936-2023 using the SPI-3 index ≤ 0 (agricultural drought) and an assessment of the variability of this number until 2045 is presented. Data from 18 meteorological stations on monthly precipitation sums were used. In particular, the following results were obtained. The features of intra-annual distribution of monthly N values in Eastern Georgia in 1936-2023 (Full period), 1936-1975 (I period) and 1984-2023 (II period) were studied. Overall, in the second period compared to the first for all stations, a trend of increasing aridity was observed in 136 cases (months), decreasing in 65 cases, and remaining constant in only 15 cases. In other words, the overall trend is toward increasing aridity.
Statistical analysis of N values in spring-autumn period was conducted. In the second period of time compared to the first, mean N values in spring-autumn period for Paravani, Tsalka, Bolnisi, Sagarejo, Gurjaani, Kvareli, Tianeti, Pasanauri and Stepantsminda are significant increase (aridity tendency). Only at one station (Lagodekhi) is observed significant decrease of this difference (wetting tendency). Insignificant variability of the values of N in second period compared to first are observed at the 8 stations: Gardabani, Tbilisi, Dedoplistskaro, Telavi, Gudauri, Gori, Khashuri and Shovi.
Statistical forecasting of N values in spring-autumn period up to 2045 was carried out. At all stations, except Tbilisi, Lagodekhi and Shovi in 2026-2045 compared to 2004-2023 on average, an increase in drought is expected.

Key words: *SPI, atmospheric precipitation, drought risk, climate change, correlation and regression analysis.*

Introduction

Drought is a phenomenon of prolonged water shortage, whether atmospheric (below-average precipitation), surface water, or groundwater. Drought can last for months or years. Atmospheric (or meteorological) droughts occur when an area receives below-average precipitation over an extended period. Meteorological droughts typically precede other types of drought. Agricultural droughts affect crop yields or the ecology of a habitat. Hydrological droughts occur when water reserves in sources such as aquifers, lakes, and reservoirs fall below the threshold required to support vegetation in the region [https://www.google.com/search?client=opera&q=засуха&sourceid=opera&ie=UTF-8&oe=UTF-8].

Currently, a large number of simple and complex indices for drought research exist [1]. Among these, one of the most commonly used is the so-called Standardized Precipitation Index (SPI), which the World Meteorological Organization recommended in 2009 as a starting point for monitoring meteorological droughts [2]. Calculating this index requires only precipitation information. The SPI is based on the probability of precipitation on any time scale. The probability of observed precipitation is then converted into an index. It is used in research and operational settings in more than 70 countries. A dedicated free program is used to calculate the SPI [3].

The SPI was developed to quantify precipitation deficits over multiple time scales or moving average windows. Meteorological conditions and soil moisture (in agriculture) respond to precipitation anomalies on relatively short time scales, such as 1-6 months. River runoff, reservoirs, and groundwater respond to longer precipitation anomalies, ranging from 6 months to 24 months or more. The SPI index for

1 or 2 months can be considered for meteorological drought, the SPI for a period of 1 to 6 months for agricultural drought. The SPI for a period of 6 to 24 months or more is used for the analysis and application of hydrological droughts [2].

In recent years, a significant number of studies on SPI variations (often in combination with other indices) have been conducted in various countries worldwide to analyze the above-mentioned drought types [4-8]. In particular, the review [8] systematically evaluates research on meteorological drought trends in Iran, focusing on the Standardized Precipitation Index (SPI) and the non-parametric Mann-Kendall (MK) test. Thirteen relevant articles were analyzed, and SPI data from 1951 to 2019 were reviewed. The review indicates that drought severity in Iran has generally increased over the past decades, particularly in arid and semi-arid regions. Northern Iran and the Caspian Sea region have not experienced significant changes, whereas the southern, southwestern, southeastern, eastern, and central regions have shown pronounced drought trends. The drought pattern in Iran is heterogeneous: northern regions display a slow trend with more variable and less predictable behavior, while the eastern and southern arid regions exhibit an increasing intensity and duration of drought periods.

Similar work is being carried out in Georgia [9-16], taking into account local climate changes [17-20]. For example, in our work [15] a detailed analysis of SPI variability for three months (agriculture drought) in eastern Georgia based on observations at 18 meteorological stations from 1936 to 2023 is presented. Study area covers 7 regions of eastern Georgia, including its capital - Tbilisi. The SPI values for seven categories was determined for three time periods (1936-2023; 1936-1975, first period; 1984-2023, second period) and probability of drought recurrence for the same time periods was determined for four categories of SPI.

In particular, it was found that in 1936-2023 that 13 points (Paravani, Tsalka, Bolnisi, Tbilisi, Sagarejo, Gurjaani, Kvareli, Telavi, Tianeti, Pasanauri, Gudauri, Stepantsminda and Khashuri) show a significant negative linear trend in SPI values. No significant changes in SPI values are observed in 4 points (Gardabani, Dedoplistskaro, Gori and Shovi). Only one point shows a positive linear trend in SPI values (Lagodekhi).

The general tendency towards aridity processes for all SPI ranges (a decrease in the difference in the repetition of SPI values in the range of categories “Extremely Wet” – “Moderately Wet” and an increase in the difference in this repetition in the range of categories “Moderately Dry” – “Extremely Dry”) in the second period of time compared to the first is observed on average for eastern Georgia and for the following points: Paravani, Tsalka, Tbilisi, Sagarejo, Tianeti, Pasanauri, Gudauri, Khashuri. Analysis of number of times in 100 years for different SPI category show that for category “Extreme Dryness” - N (Extr) - in 1984-2023, compared to 1936-1975 only four points (Lagodekhi, Gudauri, Gori, Shovi) had N (Extr) values less than critical value 2.5. In the remaining points, in the second period, the N (Extr) values were equal to or exceeded 2.5. The average N (Extr) values in the first period were 2.4, in the second – 3.0 (a general tendency for extreme drought to increase above the critical value).

In our other work [16] work detailed statistical analysis of the duration of drought periods D (months) normalized per decade for four SPI-3 categories (agriculture drought; SPI $\leq$ -1.0, $\leq$ -1.5, $\leq$ -2.0 and $\leq$ -2.5) in Eastern Georgia based on observations at the same18 meteorological stations during 1936-2023 is presented. The statistical characteristics of D values in 1936-2023, 1936-1975 and 1984-2023 were compared. The variability of D values in 1984-2023 compared to 1936-1975 (ΔD) was assessed. In particular, it was found that ΔD values are different at different points. On average, for eastern Georgia, ΔD values for all SPI categories, except $\leq$ -2.5, are increasing (i.e., an increase in the duration of droughts is observed).

This work is a continuation of two previous studies [15,16]. A detailed statistical analysis of the total number of dry months in Eastern Georgia in 1936-2023 using the SPI-3 index $\leq$ 0 (agricultural drought) and an assessment of the variability of this number until 2045 is presented below.

Study area, material and methods

Study area – Eastern Georgia (EGeo), 18 meteorological stations: Paravani (Par), Tsalka (Ts), Bolnisi (Bol), Gardabani (Gar), Tbilisi (Tb), Sagarejo (Sag), Gurjaani (Gur), Dedoplistskaro (Ded), Lagodekhi (Lag), Kvareli (Kv), Telavi (Tel), Tianeti (Tian), Pasanauri (Pas), Gudauri (Gud), Stepantsminda (St), Gori (Gori), Khashuri (Kh) and Shovi (Sh). The altitude range of meteorological stations is from 362 (Lag) to 2194 (Gud) m a.s.l. Study area covers 7 regions of Georgia, including its capital - Tbilisi. Information on coordinates and altitudes above sea level of these meteorological stations in [15] is presented.

Data of the Georgian National Environment Agency about monthly sum of atmospheric precipitation in the period from 1936 to 2023 are used. Missing data in the observation series were reconstructed using the standard method [21], taking into account representativeness of data from meteorological stations in Georgia for monthly sum of atmospheric precipitation around of these stations [22].

SPI was determined using a special program [3] for 3 months (SPI-3, agriculture drought; below – SPI). The object of the study is the total number of dry months (N) for individual stations in Eastern Georgia with SPI-3 index values ≤ 0 (agricultural drought) both in terms of their intra-annual distribution (from January to December) and for the year as a whole, and for the agricultural season (March-November).

In the proposed work 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 [21,23,24].

Forecasting the total number of dry months per agricultural season was performed using the AAA version of the exponential smoothing (ETS) algorithm taking into account the periodicity in the pre-forecast time series [25].

The total number of dry months (N) was determined for three time periods (1936-2023, full period; 1936-1975, first (I) period; 1984-2023, second (II) period). ΔN - difference between total number of dry months in 1984-2023 and 1936-1975.

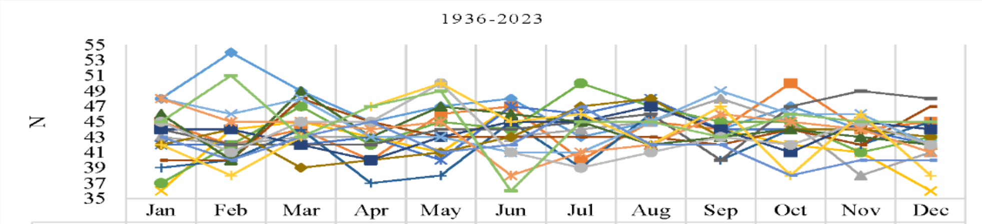
The following designations (in addition to those already indicated) will be used below: Mean – average values; Min – minimal values; Max - maximal values; Range – Max – Min; St Dev - standard deviation; C_v, - coefficient of variation, %; R – coefficient of linear correlation; R^2 – coefficient of determination; Forecast - forecast center point; 68%_Upp and 68%_Low - upper and lower levels of mean values of studied parameters; α - the level of significance; K_{DW} – Durbin-Watson statistic; a and b - coefficients of the linear regression equation $a \cdot x + b$.

Comparison of mean values of N in two forty-year of time (1984-2023 and 1936-1975) was produced with the use of Student's criterion with the level of significance α not worse than 0.3.

The degree of correlation was determined in accordance with [23]: 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 ($0 \leq R < 0.3$).

Results and discussion

Results in Fig. 1-8 and Tables 1-4 are presented.

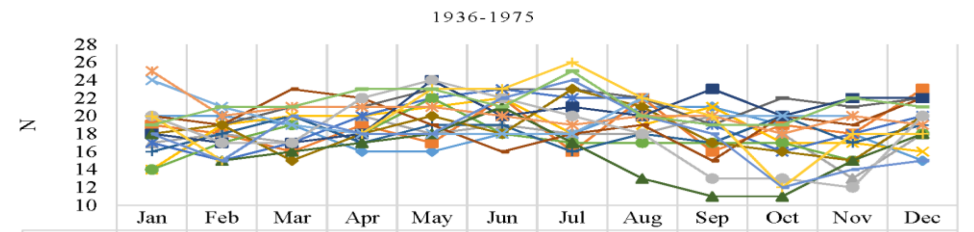


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	48	54	49	45	47	48	43	45	44	47	44	42
Ts	45	42	44	40	46	47	40	45	44	50	44	45
Bol	43	42	43	43	41	43	44	45	48	45	38	41
Gar	36	44	45	43	41	47	46	48	44	42	41	36
Tb	42	42	42	43	40	47	46	48	44	44	44	42
Sag	37	42	47	42	45	44	50	47	45	45	41	43
Gur	39	40	44	37	38	45	39	46	40	44	42	45
Ded	40	40	48	45	43	43	43	43	42	44	42	47
Lag	44	42	42	42	44	44	45	46	40	47	49	48
Kv	42	44	39	40	41	43	47	48	43	44	44	43
Tel	44	44	42	40	43	45	45	47	44	41	45	44
Tian	46	40	49	43	47	46	45	42	43	44	43	42
Pas	48	46	48	43	43	41	41	45	49	46	46	42
Gud	48	45	45	44	45	38	41	42	46	45	44	41
St	45	41	45	45	50	41	39	41	43	42	45	42
Gori	42	38	43	47	50	45	46	42	47	38	46	38
Kh	43	40	43	45	41	42	47	42	42	38	40	40
Sh	45	51	43	47	49	36	45	45	43	46	45	45

Fig. 1. Intra annual distribution of monthly N values in Eastern Georgia in 1936-2023.

In Fig. 1 data on intra annual distribution of total number of dry months in Eastern Georgia in 1936-2023 is presented. As follows from Fig. 1, N values changes from 36 (Gardabani, Jan, Dec; Shovi, Jun) to 54

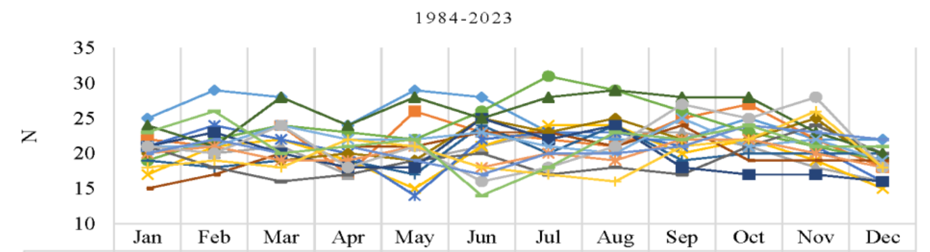
(Paravani, Feb). Mean annual values on N in 1936-2023 change from 41.6 (Gurjaani) to 46.3 (Paravani). Range between monthly values of N changes from 7 (Telavi) to 15 (Shovi).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	20	20	19	16	16	18	18	21	21	19	18	15
Ts	19	18	16	19	17	22	16	22	16	19	18	23
Bol	17	18	17	20	18	19	18	18	20	18	13	18
Gar	14	19	20	20	21	22	18	19	21	17	17	16
Tb	17	15	17	20	22	23	22	22	19	16	18	20
Sag	14	17	19	18	22	18	17	17	17	17	15	18
Gur	16	18	20	17	19	19	16	18	17	20	17	19
Ded	20	19	23	22	19	16	18	19	15	20	19	22
Lag	18	19	21	21	23	23	23	22	19	22	21	22
Kv	18	19	15	18	20	18	23	21	17	16	15	20
Tel	18	17	17	18	24	20	21	20	23	20	22	22
Tian	18	15	16	17	18	21	17	13	11	11	15	18
Pas	24	21	19	18	18	18	18	22	20	20	20	19
Gud	25	20	21	21	21	20	19	20	20	18	20	19
St	20	17	17	22	24	22	20	18	13	13	12	20
Gori	20	15	20	18	23	23	26	22	20	12	18	18
Kh	18	15	20	18	18	22	24	20	18	12	14	15
Sh	19	21	21	23	23	21	25	20	19	19	22	21

Fig. 2. Intra annual distribution of monthly N values in Eastern Georgia in 1936-1975.

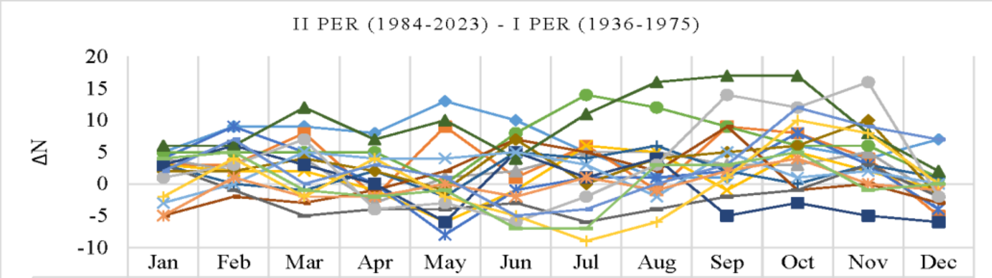
In Fig. 2 data on intra annual distribution of total number of dry months in Eastern Georgia in 1936-1975 is presented. From Fig. 2 follows, that N values changes from 11 (Tianeti, Sep, Oct) to 26 (Gori, Jul). Mean annual values on N in 1936-1975 change from 15.8 (Tianeti) to 21.2 (Lagodekhi, Shovi). Range between monthly values of N changes from 4 (Gurjaani) to 14 (Gori).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	25	29	28	24	29	28	23	22	22	25	22	22
Ts	22	21	24	17	26	23	22	21	25	27	22	18
Bol	21	20	21	17	19	21	23	23	23	21	18	16
Gar	17	21	22	19	15	21	24	24	20	22	19	15
Tb	21	24	22	20	14	22	23	23	21	24	21	16
Sag	19	22	24	23	22	26	31	29	26	23	21	19
Gur	19	18	19	19	17	24	20	24	19	20	20	20
Ded	15	17	20	21	21	23	23	21	24	19	19	19
Lag	21	18	16	17	19	20	17	18	17	21	24	20
Kv	20	21	19	20	19	25	23	25	22	22	25	18
Tel	21	23	20	18	18	25	22	24	18	17	17	16
Tian	24	21	28	24	28	25	28	29	28	28	23	20
Pas	21	21	24	22	22	23	21	20	25	21	22	19
Gud	20	21	19	19	21	18	20	19	22	22	20	18
St	21	20	24	18	21	16	18	21	27	25	28	18
Gori	18	19	18	22	21	18	17	16	21	22	26	18
Kh	20	22	20	21	19	17	20	20	21	24	23	22
Sh	23	26	20	21	22	14	18	23	22	24	21	21

Fig. 3. Intra annual distribution of monthly N values in Eastern Georgia in 1984-2023.

In Fig. 3 data on intra annual distribution of total number of dry months in Eastern Georgia in 1984-2023 is presented. As follows from Fig. 3, N values changes from 14 (Tbiisi, May; Shovi, Jun) to 31 (Sagarejo, Jul). Mean annual values on N in 1984-2023 change from 19.0 (Lagodekhi) to 25.5 (Tianeti). Range between monthly values of N changes from 4 (Gudauri) to 12 (Sagarejo, Shovi).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	5	9	9	8	13	10	5	1	1	6	4	7
Ts	3	3	8	-2	9	1	6	-1	9	8	4	-5
Bol	4	2	4	-3	1	2	5	5	3	3	5	-2
Gar	3	2	2	-1	-6	-1	6	5	-1	5	2	-1
Tb	4	9	5	0	-8	-1	1	1	2	8	3	-4
Sag	5	5	5	5	0	8	14	12	9	6	6	1
Gur	3	0	-1	2	-2	5	4	6	2	0	3	1
Ded	-5	-2	-3	-1	2	7	5	2	9	-1	0	-3
Lag	3	-1	-5	-4	-4	-3	-6	-4	-2	-1	3	-2
Kv	2	2	4	2	-1	7	0	4	5	6	10	-2
Tel	3	6	3	0	-6	5	1	4	-5	-3	-5	-6
Tian	6	6	12	7	10	4	11	16	17	17	8	2
Pas	-3	0	5	4	4	5	3	-2	5	1	2	0
Gud	-5	1	-2	-2	0	-2	1	-1	2	4	0	-1
St	1	3	7	-4	-3	-6	-2	3	14	12	16	-2
Gori	-2	4	-2	4	-2	-5	-9	-6	1	10	8	0
Kh	2	7	0	3	1	-5	-4	0	3	12	9	7
Sh	4	5	-1	-2	-1	-7	-7	3	3	5	-1	0

Fig. 4. Difference between monthly N values in 1984-2023 and 1936-1975.

In Fig. 4 data on difference between total number of dry months in Eastern Georgia in 1984-2023 and 1936-1975 is presented. As follows from Fig. 4, ΔN values changes from -9 (Gori, Jul) to 17 (Tianeti, Sep, Oct). Mean annual values on ΔN change from -2.2 (Lagodekhi) to 9.7 (Tianeti). It should be noted that the greatest trend of increasing aridity is observed in Paravani and Tianeti (for all months of the year). For the remaining stations, the trend of increasing aridity is as follows (in descending order): Sagarejo (11 months a year); Bolnisi (10); Tsalka and Kvareli (9 each); Tbilisi, Gurjaani, Pasanauri and Khashuri (8 each); Gardabani and Stepantsminda (7 each); Telavi (6); Dedoplistskaro, Gori and Shovi (5 each); Gudauri (4); Lagodekhi (2 months a year). Overall, for all stations, a trend of increasing aridity was observed in 136 cases (months), decreasing in 65 cases, and remaining constant in only 15 cases. In other words, the overall trend is toward increasing aridity.

In Table 1 information on annual and spring-autumn period data on the N values in Georgia in 1936-2023 is presented.

Table 1. Annual and spring-autumn period data on the N values in Eastern Georgia in 1936-2023. Share = 100·(Mar-Nov)/Year, %.

Period	Loc	Year	Mar-Nov	Share, %	Loc	Year	Mar-Nov	Share, %
Full	Par	556	412	74.1	Kv	518	389	75.1
II		299	223	74.6		259	200	77.2
I		221	166	75.1		220	163	74.1
II-I		78	57	-0.5		39	37	3.1
Full	Ts	532	400	75.2	Tel	524	392	74.8

II		268	207	77.2		239	179	74.9
I		225	165	73.3		242	185	76.4
II-I		43	42	3.9		-3	-6	-1.6
Full	Bol	516	390	75.6	Tian	530	402	75.8
II		243	186	76.5		306	241	78.8
I		214	161	75.2		190	139	73.2
II-I		29	25	1.3		116	102	5.6
Full	Gar	513	397	77.4	Pas	538	402	74.7
II		239	186	77.8		261	200	76.6
I		224	175	78.1		237	173	73.0
II-I		15	11	-0.3		24	27	3.6
Full	Tb	524	398	76.0	Gud	524	390	74.4
II		251	190	75.7		239	180	75.3
I		231	179	77.5		244	180	73.8
II-I		20	11	-1.8		-5	0	1.5
Full	Sag	528	406	76.9	St	519	391	75.3
II		285	225	78.9		257	198	77.0
I		209	160	76.6		218	161	73.9
II-I		76	65	2.4		39	37	3.2
Full	Gur	499	375	75.2	Gori	522	404	77.4
II		239	182	76.2		236	181	76.7
I		216	163	75.5		235	182	77.4
II-I		23	19	0.7		1	-1	-0.8
Full	Ded	520	393	75.6	Kh	503	380	75.5
II		242	191	78.9		249	185	74.3
I		232	171	73.7		214	166	77.6
II-I		10	20	5.2		35	19	-3.3
Full	Lag	533	399	74.9	Sh	540	399	73.9
II		228	169	74.1		255	185	72.5
I		254	195	76.8		254	193	76.0
II-I		-26	-26	-2.6		1	-8	-3.4

As follows from Table 1 annual values of N in 1936-2023 change from 499 (Gurjaani) to 556 (Paravani) with mean value – 524; range – 57. Spring-autumn values of N in 1936-2023 change from 375 (Gurjaani) to 412 (Paravani) with mean value – 396; range – 37. Share spring-autumn values of N from annual change from 73.9 % (Shovi) to 77.4 % (Gori) with mean value 75.4 %; range – 3.5 %.

Annual values of N in 1936-1975 change from 190 (Tianeti) to 254 (lagodekhi) with mean value – 227; range – 64. Spring-autumn values of N in 1936-1975 change from 139 (Tianeti) to 195 (lagodekhi) with mean value – 171; range – 56. Share spring-autumn values of N from annual change from 73.0 % (Pasanauri) to 78.1 % (Gardabani) with mean value 75.4 %; range – 5.1 %.

Annual values of N in 1984-2023 change from 228 (Lagodekhi) to 306 (Tianeti) with mean value – 255; range – 78. Spring-autumn values of N in 1984-2023 change from 169 (Lagodekh) to 241 (Tianeti) with mean value – 195; range – 72. Share spring-autumn values of N from annual change from 72.5 % (Shovi) to 78.9 % (Dedoplistskaro) with mean value 76.3 %; range – 6.4 %.

Annual values of ΔN change from -26 (Lagodekhi) to 116 (Tianeti) with mean value – 29; range – 142. Spring-autumn values of ΔN change from -26 (Lagodekhi) to 102 (Tianeti) with mean value – 24; range – 128. Difference between of share spring-autumn values of ΔN from annual in 1984-2023 and 1936-1975 change from -3.4 % (Shovi) to 5.6 % (Tianeti) with mean value 0.9 %; range – 9.0 %.

Table 2. Statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1936-2023. R_{min} = 0.12, α = 0.25

Per	1936-2023								
Loc	Max	Min	Mean	St Dev	C_v, %	a	b	R	K_{DW}
Par	9	0	4.7	2.5	53.1	0.024198	3.605016	0.25	1.95
Ts	9	0	4.5	2.4	53.4	0.021028	3.609718	0.22	1.89
Bol	9	0	4.4	2.3	51.5	0.013015	3.852665	0.15	1.86
Gar	9	0	4.5	2.4	53.5	0.00085	4.47335	0.01	1.87
Tb	9	0	4.5	2.3	50.4	0.005248	4.289185	0.06	1.78
Sag	9	0	4.6	2.7	59.1	0.028953	3.325235	0.27	2.21
Gur	9	0	4.3	2.2	51.1	0.009184	3.852665	0.11	2.16
Ded	9	0	4.5	2.4	54.0	0.010417	4.002351	0.11	2.09
Lag	9	0	4.5	2.4	52.7	-0.01734	5.305643	0.19	1.72
Kv	9	0	4.4	2.4	54.0	0.017056	3.661442	0.18	1.92
Tel	9	0	4.5	2.3	51.7	0.003381	4.304075	0.04	1.85
Tian	9	0	4.6	2.6	57.6	0.054436	2.145768	0.53	2.09
Pas	9	0	4.6	2.4	53.6	0.020394	3.660658	0.21	1.90
Gud	9	0	4.4	2.5	55.7	0.006058	4.162226	0.06	1.75
St	9	0	4.4	2.5	55.3	0.02153	3.48511	0.22	1.82
Gori	9	0	4.6	2.2	48.7	-0.00113	4.641066	0.01	2.18
Kh	9	0	4.3	2.4	55.5	0.010972	3.829937	0.12	2.47
Sh	9	0	4.5	2.5	54.1	-0.00103	4.579937	0.01	2.04
EGeo	8.2	0.8	4.5	1.6	35.1	0.013837	3.88652	0.22	2.00

In Table 2 statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1936-2023 are presented. In particular, from Table 3 follows, that mean N values changes from 4.3 (Khashuri) to 4.7 (Pasanauri) with average value (EGeo) – 4.5; range – 0.4. The temporal variation of N values for individual stations and for eastern Georgia as a whole (averaged across all stations) is approximated by a linear function (the corresponding K_{DW} values indicate the absence of autocorrelation in the residuals). A significant positive trend in the average spring-autumn N values is observed for EGeo and all stations except Gardabani, Tbilisi, Telavi, Gudauri, Gori, and Shovi. For Lagodekhi, this trend is negative. For Gardabani, Gori, and Shovi, there is no trend.

Table 3. Statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1984-2023 and 1936-1975.

Per	1936-1975					1984-2023				
Loc	Max	Min	Mean	St Dev	C_v, %	Max	Min	Mean	St Dev	C_v, %
Par	9	0	4.2	2.4	58.4	9	0	5.6	2.3	40.8
Ts	9	0	4.1	2.1	51.8	9	0	5.2	2.5	49.1
Bol	9	0	4.0	2.5	62.3	9	0	4.7	2.1	44.2
Gar	9	0	4.4	2.6	59.4	9	0	4.7	2.2	48.1
Tb	9	0	4.5	2.5	55.0	9	0	4.8	2.2	46.7
Sag	9	0	4.0	2.6	65.3	9	0	5.6	2.7	47.2
Gur	9	0	4.1	2.2	54.6	9	1	4.6	2.1	45.1
Ded	9	0	4.3	2.4	56.1	8	0	4.8	2.4	50.3
Lag	9	0	4.9	2.2	44.8	9	0	4.2	2.5	60.3
Kv	9	0	4.1	2.5	61.2	9	1	5.0	2.2	44.8
Tel	9	0	4.6	2.4	51.7	9	0	4.5	2.2	49.6
Tian	8	0	3.5	2.2	64.5	9	1	6.0	2.4	39.3
Pas	9	0	4.3	2.4	56.5	9	0	5.0	2.5	50.8
Gud	9	0	4.5	2.5	55.4	9	0	4.5	2.6	57.8
St	9	0	4.0	2.4	60.5	9	1	5.0	2.6	51.7

Gori	8	0	4.6	2.2	49.0	8	0	4.5	2.3	49.8
Kh	9	0	4.2	2.4	57.6	8	0	4.6	2.4	52.2
Sh	9	0	4.8	2.6	53.7	9	1	4.6	2.3	49.4
EGeo	8.2	0.8	4.3	1.6	38.0	7.4	0.9	4.9	1.5	30.5

Statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1936-1975 and 1984-2023 in Table 3 is presented. As follows from Table 3 mean values of N in 1936-1975 changes from 3.5 (Tianeti) to 4.9 (Lagodekhi) with average value (EGeo) – 4.3; range – 1.4. In 1984-2023 mean N values changes from 4.2 (Lagodekhi) to 6.0 (Tianeti) with average value (EGeo) – 4.9; range – 1.8.

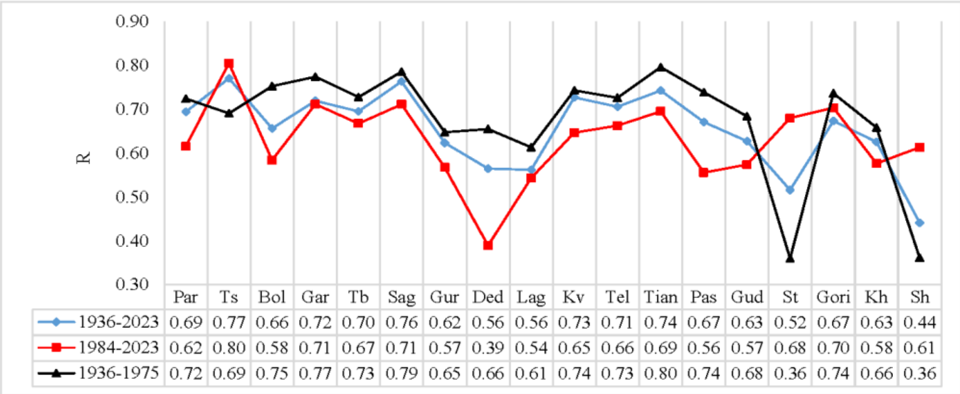


Fig. 5. Linear correlation between EGeo and another location on N values in spring-autumn period in 1936-2023, 1984-2023 and 1936-1975.

Linear correlation between EGeo and another location on N values in spring-autumn period (Fig. 5) in 1936-2023 change from 0.44 (pair: EGeo÷Shovi, low correlation) to 0.77 (pair: EGeo÷Tsalka, high correlation) with average value – 0.65 (moderate correlation), in 1936-1975 – from 0.36 (pair: EGeo÷ Shovi, low correlation) to 0.80 (pair: EGeo÷Tianeti, high correlation) with average value – 0.68 (moderate correlation) and in 1984-2023 from 0.39 (pair: EGeo÷Dedoplistskaro, low correlation) to 0.80 (pair: EGeo÷Tsalka, high correlation) with average value – 0.63 (moderate correlation).

In general, in the second period of time, compared to the first, the correlation links between the studied parameters worsened: average values were 0.63 and 0.68, respectively, and high correlation for 10 and 4 pairs, respectively (Fig. 5).

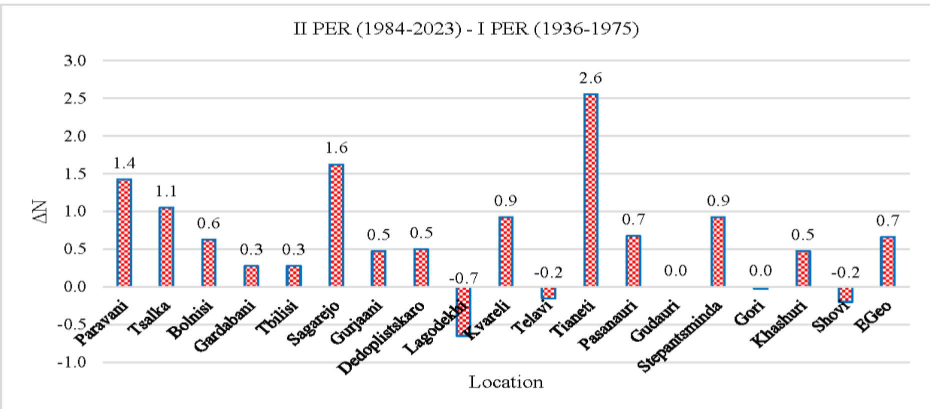


Fig. 6. Difference between mean N values in spring-autumn period in 1984-2023 and 1936-1975 in Eastern Georgia.

As noted above (Fig. 4, Table 3), a trend toward aridity was observed in Eastern Georgia during the second period compared to the first. This is also clearly evident in Fig. 6 for ΔN mean values in spring-autumn period. As follows from Fig. 6, values of ΔN changes from -0.7 (Lagodekhi) to 2.6 (Tianeti); for EGeo ΔN = 0.7. Insignificant variability of the values of ΔN are observed at the 8 stations: Gardabani, Tbilisi, Dedoplistskaro, Telavi, Gudauri, Gori, Khashuri and Shovi. Only at one station (Lagodekhi) is observed significant decrease value of ΔN (wetting tendency). At the remaining 9 stations: Paravani, Tsalka, Bolnisi, Sagarejo, Gurjaani, Kvareli, Tianeti, Pasanauri and Stepantsminda are observed significant increase value of ΔN (aridity tendency).

Finally, in Fig. 7 and Fig. 8 examples of forecasts of N values in the spring-autumn period 2025-2045 for Stepantsminda (periodicity – 22 year) and Tianeti (without periodicity) are presented. In Table 4 data about comparison of the real (2004-2023) and forecasted (2026-2045) mean N values in spring-autumn period in Eastern Georgia is presented.

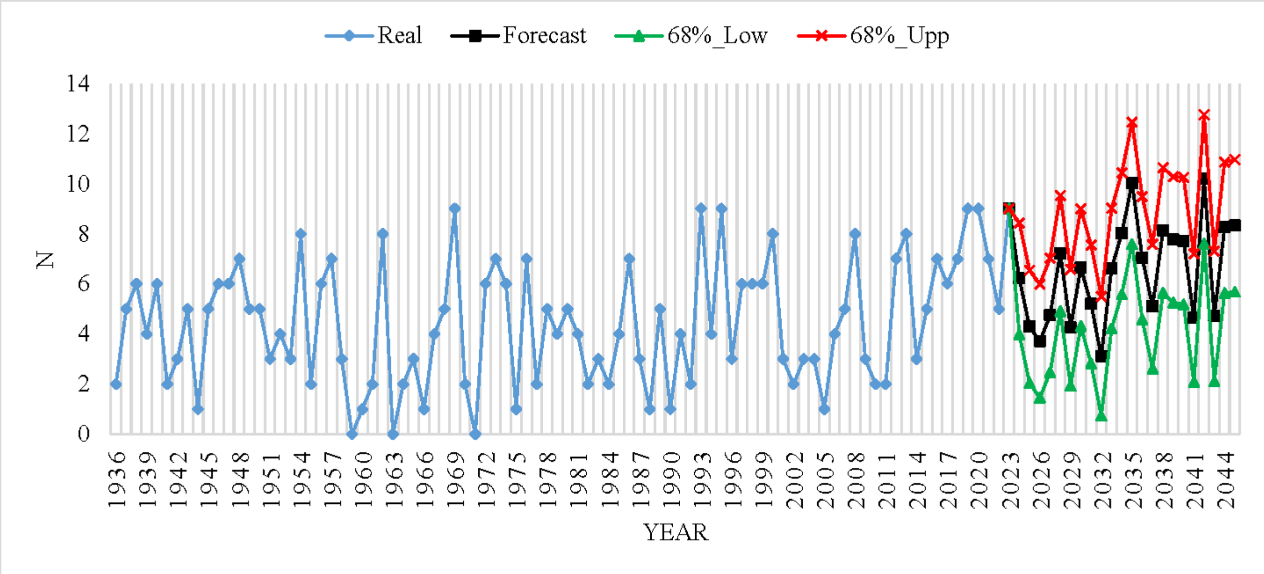


Fig. 7. Forecast of N values in the spring-autumn period 2025-2045 for Stepantsminda (periodicity – 22 year)

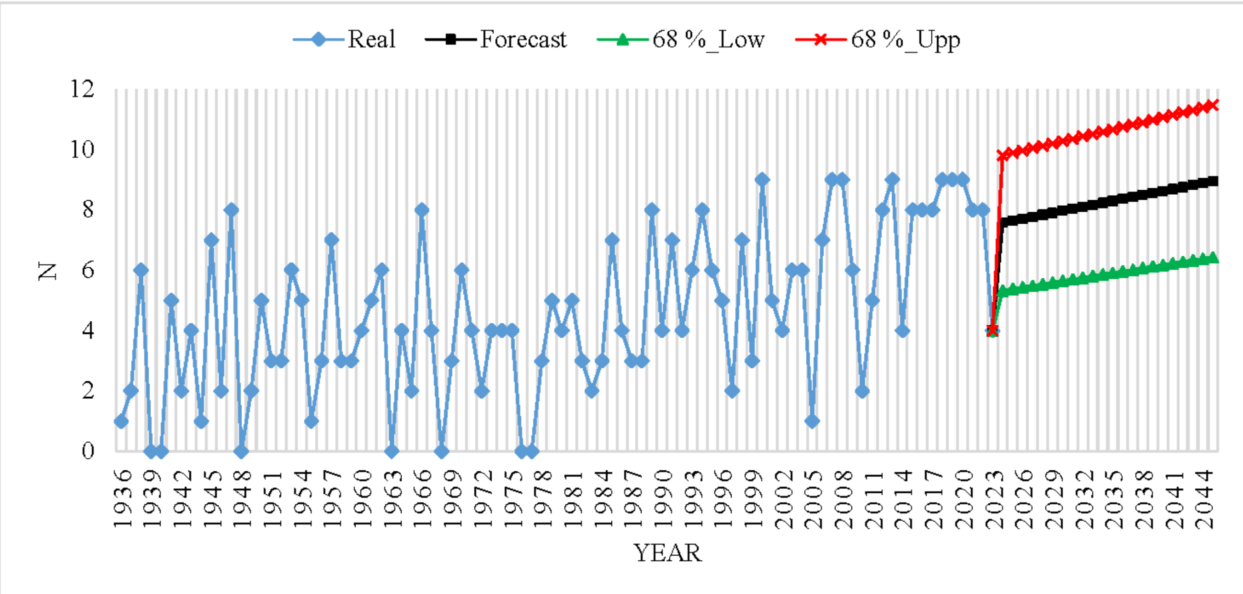


Fig. 8. Forecast of N values in the spring-autumn period 2025-2045 for Tianeti (without periodicity).

Table 4. Comparison of the real (2004-2023) and forecasted (2026-2045) mean N values in spring-autumn period in Eastern Georgia.

Period	2004-2023			2026-2045			
Location	Mean Real	68%_Low	68%_Upp	Mean Forecast	68%_Low	68%_Upp	Periodicity, Year
Paravani	4.8	4.2	5.3	6.1	2.9	9.3	no
Tsalka	5.6	4.9	6.2	6.9	4.2	9.5	no
Bolnisi	4.2	3.7	4.6	4.9	2.3	7.5	no
Gardabani	4.0	3.5	4.5	4.7	1.2	8.1	no
Tbilisi	4.3	3.7	4.8	3.5	1.0	6.5	22
Sagarejo	5.4	4.7	6.1	6.8	3.9	9.8	no
Gurjaani	4.2	3.7	4.6	4.6	2.1	7.2	29
Dedoplistskaro	5.5	4.9	6.0	8.2	5.9	10.5	no
Lagodekhi	3.1	2.7	3.5	2.8	0.2	5.5	no
Kvareli	4.8	4.2	5.3	5.8	3.0	8.5	no
Telavi	4.1	3.6	4.6	5.1	2.5	7.7	no
Tianeti	6.9	6.3	7.4	8.3	5.9	10.7	no
Pasanauri	5.0	4.4	5.6	6.7	4.0	9.4	no
Gudauri	4.8	4.1	5.4	6.3	3.4	9.1	6
Stepantsminda	5.5	4.9	6.1	6.6	4.1	9.0	22
Gori	4.1	3.6	4.6	4.5	1.9	7.1	no
Khashuri	4.8	4.2	5.4	5.7	3.3	8.1	no
Shovi	4.8	4.2	5.3	2.5	0.6	5.1	22
EGeo	4.7	4.4	5.1	5.7	3.9	7.6	no

In particular, as follows from Table 4, at all stations, except Tbilisi, Lagodekhi and Shovi in 2026-2045 compared to 2004-2023 on average, an increase in drought is expected.

Conclusion

In the future, it is planned to conduct detailed comprehensive studies of SPI for 1, 3, 6, 9 and 12 months, based on data from 39 meteorological stations in Georgia in 1936-2023.

Acknowledgments

The research was funded by Shota Rustaveli National Scientific Foundation Grant No. FR-22-18445.

References

[1] Handbook of Drought Indicators and Indices. WMO-No. 1173, 2016, 52 p., https://www.droughtmanagement.info/literature/GWP_Handbook_of_Drought_Indicators_and_Indices_2016.pdf

[2] Standardized Precipitation Index User Guide - WMO, No 1090, 2012, 24 p. https://www.droughtmanagement.info/literature/WMO_standardized_precipitation_index_user_guide_en_2012.pdf

[3] National Drought Mitigation Center - SPI Generator [software]. University of Nebraska–Lincoln, 2018. https://drought.unl.edu/Monitoring/SPI/SPIProgram.aspx

[4] Lloyd-Hughes, B., Saunders, M., A. A Drought Climatology for Europe - International Journal of Climatology: a Journal of the Royal Meteorological Society, vol. 22, No. 13, 2002, pp. 1571-1592. https://doi.org/10.1002/joc.846

[5] Yaseen, Z., M., Ali, M., Sharafati, A., Al-Ansari N., Shahid, S. Forecasting Standardized Precipitation Index using Data Intelligence Models: Regional Investigation of Bangladesh - Scientific reports, vol. 11, 2021, e3435. https://doi.org/10.1038/s41598-021-82977-9

[6] Maximova, N., B., Pochyomin, N., M., Morkovkin, G., G., Slazhneva, S., S. Application of the Standardized Precipitation Index for the Assessment and Forecast of Atmospheric Droughts in Altai Krai -Siberian Journal of Life Sciences and Agriculture, vol. 14, No. 3, 2022, pp. 377-391. DOI: 10.12731/2658-6649-2022-14-3-377-391
[7] Bio Sidi, D., Bouko, A., A., Gao, B., Abubakar, J., Annan, R., F., Djessou, R., D., Mutelo, A.,M., El-Saadani, Z., Dehah, L. Characteristics of Meteorological Droughts Across Different Climatic Zones in Benin - Atmosphere, 16, 611, 2025, 22 p. https://doi.org/10.3390/atmos16050611
[8] Keshavarz A. Trends in Meteorological Drought in Iran Using the SPI Index and Mann-Kendall Test: A Comprehensive Review. Journal of Asian Geography, Volume 4 (Issue 2), 2025, 79-83. https://doi.org/10.36777/jag2025.4.2.8
[9] Tatishvili, M., R., Palavandishvili, A., M., Tsitsagi, M., B., Suknidze N., E. The Use of Structured Data for Drought Evaluation in Georgia - Journal of Georgian Geophysical Society, vol. 25, No.1, 2022. https://doi.org/10.48614/ggs2520224806
[10] Tatishvili, M., Palavandishvili, A., Tsitsagi, M., Gulashvili, Z., Suknidze, N. Drought Evaluation Based on Spei, Spi Indices for Georgian Territory - Int. Conf. of Young Scientists "Modern Problems of Earth Sciences", Proceedings, ISBN 978-9941-36-044-2, Publish House of Iv. Javakhishvili Tbilisi State University, Tbilisi, November 21-22, 2022, pp. 119-121.
[11] Tsitsagi M., Gulashvili Z., Bolashvili N., Tatishvili M., Suknidze N. Relationship Between Normalised Difference Vegetation Index, Precipitation and Drought Indices (Case of Kakheti, Georgia). 22nd International Multidisciplinary Scientific GeoConference SGEM, 2022. https://doi.org/10.5593/sgem2022/4.1/s19.46
[12] Tatishvili M., Palavandishvili A., Tsitsagi M., Suknidze, N. The Big Data for Drought Monitoring in Georgia. In: Geibel R.C., Machavariani S. (eds) Chances and Challenges of Digital Management. ISPC 2022. Springer Proceedings in Business and Economics, Springer, Cham., 2023. https://doi.org/10.1007/978-3-031-45601-5_13
[13] Tatishvili, M., Kapadze, N., Mkurnalidze, I., Palavandishvili, A. Drought Evaluation in Georgia using SPI and SpEI Indices. Proceedings – Int. Sc. Conf. “Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country”, Proceedings, ISBN 978-9941-36-272-9, Tbilisi, Georgia, October 17-19, 2024, pp. 96 – 100, Publish House of Iv. Javakhishvili Tbilisi State University.
[14] Tsitsagi, M., Gulashvili Z., Palavandishvili A., Tatishvili M., Nanuli Zotikishvili, N. - Difficulties in Estimating the Negative Ecological and Economic Impacts of Droughts in Georgia - Transactions IHM, GTU, vol.136, 2025, pp.109-119, (in Georgian).
[15] Amiranashvili A., DavitashviliT., Kharshiladze O., Samkharadze I., Amilakhvari D. Drought Risk Assessment in Eastern Georgia Using SPI-3 Index under Regional Climate Change in 1936-2023. Int. Journal of Sustainability and Rick Control, e-ISSN: 3104-8358, p-ISSN: 3104-834X, Baku, Azerbaijan, Vol. 1, No. 3 (3), December 2025, pp. 30-37. DOI: 10.64599/UOSY4215; https://www.elibrary.ru/item.asp?id=84715949
[16] Amiranashvili A., Davitashvili T., Kharshiladze O., Samkharadze I., Amilakhvari D. Drought Periods Assessment in Eastern Georgia using SPI-3 Index in 1936-2023. 1st International Scientific Conference “Modern problems in Geophysics”. Proceedings, ISBN 978-9941-36-434-1, ISSN 3088-4349, Tbilisi, Georgia, November 6-8, 2025. Publish House of Iv. Javakhishvili Tbilisi State University, Tbilisi, 2025, pp. 121-124. http://openlibrary.ge/bitstream/123456789/10767/1/31_Conf_MPG_2025.pdf
[17] Bliadze, T., Gvasalia, G., Kirkitadze, D., Mekoshkishvili, N. Changeability of the Atmospheric Precipitations Regime in Kakheti in 1956-2015. Proceedings – Int. Sc. Conf. “Natural Disasters in Georgia: Monitoring, Prevention, Mitigation”. ISBN 978-9941-13-899-7, December 12-14, Tbilisi, 2019, pp. 74-77, Publish House of Iv. Javakhishvili Tbilisi State University.
[18] Amiranashvili, A., Bliadze, T., Kartvelishvili, L. Statistical Characteristics of Monthly Sums of Atmospheric Precipitations in Tianeti (Georgia) in 1956-2015 - Trans. of Mikheil Nodia institute of Geophysics, ISSN 1512-1135, vol. 70, Tb., 2019, pp. 112-118, (in Russian), http://dspace.gela.org.ge/handle/123456789/254
[19] Kartvelishvili, L., Tatishvili, M., Amiranashvili, A., Megrelidze, L., Kutaladze, N. Weather, Climate and their Change Regularities for the Conditions of Georgia. Publishing House “UNIVERSAL”, Tbilisi, 2023, 406 p.
[20] Bolashvili, N., Chikhladze, V., Kartvelishvili, L., Tatishvili, M. Variability of Atmospheric Precipitation in Tbilisi in 1844-2023. Proceedings – Int. Sc. Conf. “Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country”, ISBN 978-9941-36-

272-9, Tbilisi, Georgia, October 17-19, 2024, pp. 150 – 154, Publish House of Iv. Javakhishvili Tbilisi State University. http://dspace.gela.org.ge/bitstream/123456789/10620/1/38_MM-180.pdf
[21] Kobisheva, N., Narovlianski, G. Climatological processing of the meteorological information. Leningrad, 1978, 294 p., Gidrometeoizdat, (in Russian).
[22] Amiranashvili, A., Chelidze, T., Svanadze, D., Tsamalashvili, T., Varamashvili, N. About the Representativeness of Data from Meteorological Stations in Georgia for Monthly Sum of Atmospheric Precipitation Around of These Stations. 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(1), 2024, pp. 52–57. https://ggs.openjournals.ge/index.php/GGS/article/view/7983
[23] Hinkle, D., E., Wiersma, W., Jurs, S., G. Applied Statistics for the Behavioral Sciences - Boston, MA, Houghton Mifflin Company, ISBN: 0618124055; 9780618124053, 2003, 756 p.
[24] Kendall M.G. Time-series. Moscow, 1981, 200 p., (in Russian).
[25] Box G.E.P., Jenkins G.M., Reinsel G.C. Time Series Analysis: Forecasting & Control (3rd Edition). ISBN10: 0130607746, ISBN13: 9780130607744, Prentice Hall, 1994, 592 p.

აღმოსავლეთ საქართველოში 1936-2023 წწ. მშრალი თვეების საერთო რაოდენობის სტატისტიკური ანალიზი SPI-3 ინდექსის ≤ 0 გამოყენებით და ამ რაოდენობის ცვალებადობის შეფასება 2045 წლამდე

ა. ამირანაშვილი, თ. დავითაშვილი, ო. ხარშილაძე,
ი. სამხარაძე, დ. ამილახვარი

რეზიუმე

სტატიაში წარმოდგენილია აღმოსავლეთ საქართველოში მშრალი თვეების (N) საერთო რაოდენობის დეტალური სტატისტიკური ანალიზი 1936-2023 წწ. SPI-3 ≤ 0 ინდექსის (სოფლის მეურნეობის გვალვა) გამოყენებით და მისი ცვალებადობის შეფასება 2045 წლამდე. გამოყენებული იქნა 18 მეტეოროლოგიური სადგურიდან მიღებული ყოველთვიური ნალექების რაოდენობის მონაცემები. კერძოდ, მიღებული იქნა შემდეგი შედეგები.
შესწავლილი იქნა აღმოსავლეთ საქართველოში ყოველთვიური N მნიშვნელობების შიდა წლიური განაწილების თავისებურებები 1936-2023 წწ. (სრული პერიოდი), 1936-1975 წწ. (I პერიოდი) და 1984-2023 წწ. (II პერიოდი). ზოგადად, მეორე პერიოდში, პირველთან შედარებით, ყველა სადგურისთვის დაფიქსირდა არიდობის ზრდის ტენდენცია 136 შემთხვევაში (თვეები), შემცირებისკენ 65 შემთხვევაში და მუდმივი მნიშვნელობის შენარჩუნებისკენ მხოლოდ 15 შემთხვევაში. სხვა სიტყვებით რომ ვთქვათ, საერთო ტენდენცია არიდობის ზრდისკენაა.
ჩატარდა გაზაფხული-შემოდგომის პერიოდში N მნიშვნელობების სტატისტიკური ანალიზი. მეორე პერიოდში, პირველთან შედარებით, გაზაფხული-შემოდგომის პერიოდში ფარავნის, წალკის, ბოლნისის, საგარეჯოს, გურჯაანის, ყვარლის, თიანეთის, ფასანაურის და სტეფანწმინდის საშუალო N მნიშვნელობები მნიშვნელოვნად იზრდება (არიდულობის ტენდენცია). მხოლოდ ერთ სადგურზე (ლაგოდეხი) შეინიშნება ამ სხვაობის მნიშვნელოვანი შემცირება (ნესტის ტენდენცია). პირველთან შედარებით მეორე პერიოდში N მნიშვნელობების უმნიშვნელო ცვალებადობა შეინიშნება რვა სადგურზე: გარდაბანი, თბილისი, დედოფლისწყარო, თელავი, გუდაური, გორი, ხაშური და შოვი.
ჩატარდა გაზაფხული-შემოდგომის პერიოდის N მნიშვნელობების სტატისტიკური პროგნოზირება 2045 წლამდე. ყველა სადგურზე, გარდა თბილისის, ლაგოდეხის და შოვისა, მოსალოდნელია გვალვის ზრდა 2026-2045 წწ. 2004-2023 წწ. საშუალო მაჩვენებელთან შედარებით.

საკვანძო სიტყვები: გვალვის ინდექსი (SPI), ნალექი, გვალვის რისკი, კლიმატის ცვლილება, კორელაციული და რეგრესიული ანალიზი.

Статистический анализ общего количества засушливых месяцев в Восточной Грузии в период 1936-2023 гг. с использованием индекса SPI-3 ≤ 0 и оценка изменчивости этого количества до 2045 года

А. Амиранашвили, Т. Давиташвили, О. Харшиладзе, И. Самхарадзе, Д. Амилахвари

Резюме

Представлен подробный статистический анализ общего числа засушливых месяцев (N) в Восточной Грузии в 1936-2023 гг. с использованием индекса SPI-3 ≤ 0 (сельскохозяйственная засуха) и оценка изменчивости этого числа до 2045 года. Использованы данные с 18 метеорологических станций о ежемесячных суммах осадков. В частности, были получены следующие результаты.

Изучены особенности внутригодового распределения ежемесячных значений N в Восточной Грузии в 1936-2023 гг. (полный период), 1936-1975 гг. (I период) и 1984-2023 гг. (II период). В целом, во втором периоде по сравнению с первым для всех станций наблюдалась тенденция к увеличению засушливости в 136 случаях (месяцах), к уменьшению в 65 случаях и к сохранению постоянного значения только в 15 случаях. Другими словами, общая тенденция направлена к увеличению засушливости.

Проведен статистический анализ значений N в весенне-осенний период. Во второй период по сравнению с первым средние значения N в весенне-осенний период для Паравани, Цалки, Болниси, Сагареджо, Гурджаани, Кварели, Тианети, Пасанаури и Степанцминды значимо увеличиваются (тенденция к засушливости). Только на одной станции (Лагодехи) наблюдается значимое уменьшение этой разницы (тенденция к увлажнению). Незначимая изменчивость значений N во втором периоде по сравнению с первым наблюдается на 8 станциях: Гардабани, Тбилиси, Дедоплистскаро, Телави, Гудаури, Гори, Хашури и Шови.

Было проведено статистическое прогнозирование значений N в весенне-осенний период до 2045 года. На всех станциях, за исключением Тбилиси, Лагодехи и Шови, в 2026-2045 гг. по сравнению со средними показателями 2004-2023 гг. ожидается увеличение засухи.

Ключевые слова: индекс засухи (SPI), атмосферные осадки, риск засухи, изменение климата, корреляционный и регрессионный анализ.