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(1), 2025, pp. 50 - 63

Statistical Analysis of Annual and Semi-Annual Sum of Atmospheric Precipitation Data for 59 Municipalities (11 Regions) of Georgia with Landslide Hazard Zones from 2015 to 2024

[1]Avtandil G. Amiranashvili, [2]Luca Brocca, [1]Tamaz L. Chelidze, [1]David T. Svanadze, [3]Tamar N. Tsamalashvili, [1]Nodar D. Varamashvili

[1]M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University, Tbilisi, Georgia
avtandilamiranashvili@gmail.com
[2]Research Institute for Geo-Hydrological Protection, Perugia, Italy
[3]A. Janelidze Geological Institute of I. Javakhishvili Tbilisi State University, Tbilisi, Georgia

ABSTRACT

The article presents the results of statistical analysis of data from 62 meteorological stations of Georgia located in the territories of 59 municipalities (11 regions) of Georgia with dangerous landslide zones on semi-annual and annual sum of atmospheric precipitation. The observation period is from 2015 to 2024. In particular, empirical (map) and calculated model of distribution of annual sum of atmospheric precipitation averaged over the territories of municipalities were obtained; the relationships of semi-annual and annual sum of atmospheric precipitation averaged over the territories of municipalities and regions with the altitude and longitude of the area, etc. were studied. In the future, it is planned to use the results of this work for a more detailed study of the relationship between precipitation and the activation of landslide processes on a climatic time scale.

Key words: *atmospheric precipitations, correlation and regression analysis, natural catastrophe, landslides.*

Introduction

Atmospheric precipitation, as one of the most important climate-forming factors, has long been the subject of research in various countries of the world [1-13], including Georgia [14-17]. Considering that the territory of Georgia is known for its diversity of climatic zones, increased attention is paid to the study of the variability of the precipitation regime here, especially against the background of observed and expected changes in the global climate [18].

For example, a large number of studies have been conducted on the climatology of annual, seasonal, monthly and daily precipitation amounts [19-24]; the role of precipitation in the formation of bioclimatic conditions of territories [25,26]; the influence of precipitation deficit and excess on the provocation of droughts [27-29], floods [30,31], landslides, mudflows [32], other negative phenomena [33,34], etc. The representativeness of the data of meteorological stations of Georgia on the annual, semi-annual and monthly amount of atmospheric precipitation around these stations was studied [35,36]. The study of the relationships between ground-based and satellite data on atmospheric precipitation has begun [37-40]. In recent years, an analysis of the applicability of various precipitation forecasting models [41,42], as well as the use of an integrated hybrid approach to forecasting various events associated with natural disasters [43] has been carried out.

In particular, as a result of the analysis of data from 39 meteorological stations of Georgia on atmospheric precipitation from 1936 to 2015, it was established that, in general, for the year, the data of meteorological stations on precipitation are representative around these stations at a distance of 19 km (Mta-Sabueti, Kobuleti) to 46 km (Gori); in the cold period of the year - from 13 km (Mta-Sabueti) to 49 km (Zugdidi); in the warm period of the year - from 20 km (Chokhatauri) to 43 km (Pasanauri); for monthly precipitation amounts - from 14 km (Akhalkalaki, January) to 90 km (Akhaltsikhe, October). The paper [38] presents information on the linear regression coefficients between satellite and ground-based data on annual and semi-annual precipitation sum for 26 points in Georgia for 2001–2020.

It is known that the time scale of the influence of atmospheric precipitation on the provocation of various natural disasters (including landslides and mudflows) has a wide range - from several tens of minutes to several days, months and years (climatic time scale). A whole series of studies were carried out by us in [44-51].

For example, in [45] preliminary results of the study of the relationship between the variability of the mean annual sum of atmospheric precipitation and landslide processes in Georgia for 32 years are presented. In particular, it was found that with an increase in the annual sum of atmospheric precipitation, the tendency of increase in the number of landslides is observed in accordance with a second power of polynomial.

Some results of statistical analysis of long-term variations of annual amount of atmospheric precipitation for 21 meteorological stations of Georgia (P) located in areas with landslides, average annual amount of precipitation for these stations (P_a), relationship between the P_a and number of re-activated and new cases of landslides (LS), and the estimated values of LS up to 2045 using predictive data on P_a are presented in [47]. Data from the Environmental Agency of Georgia on the P in period 1936 - 2020 and data on LS in period 1996 – 2018 are used.

The forecast of P_a using the AAA version of the Exponential Smoothing (ETS) algorithm was carried out.

In particular, the following results are obtained.

The correlations between the annual amounts of P at each of the meteorological stations with averaged data for all 21 stations P_a are established.

In 1981-2020, compared with 1936-1975, no significant variability of the mean P values is observed at 11 stations, an increase - at 6 stations, and a decrease - at 4 stations. The P_a value do not change during the indicated time periods.

The forecast of the P_a value up to 2040 were estimated taking into account the periodicity of precipitation variability, which is 11 years.

A cross-correlation analysis of the time series of the P_a and LS values showed that the best correlation between the indicated parameters is observed with a five-year advance of precipitation data. With this in mind, a linear regression equation was obtained between the five-year moving average of the P_a and the five-year moving average of the LS values.

Using this equation and predictive P_a data, five-year moving averages of re-activated and new landslides cases up to 2045 were estimated.

The accumulation of new and systematization of existing information on various natural disasters in Georgia (storm winds, floods, landslides, mudflows, hail, etc.) [52,53] allows for a more qualitative scientific analysis of these events, as well as for clarifying the degree and scale of their impact on the environment [54-59].

In particular, a series of geological bulletins [53] presents detailed data on precipitation patterns and various geological processes (including landslides) for almost all municipalities of Georgia from 2015 to 2024.

This work is a continuation of previous studies related to the study of the relationship between precipitation and the activation of landslide processes on a climatic time scale. Below is the first part of the work, concerning the statistical analysis of data on annual and semi-annual precipitation amounts for 59 municipalities of Georgia for which there are data on landslides causing damage to the environment [53], from 2015 to 2024.

Study area, material and methods

Study area – 11 region of Georgia including 59 municipalities with registered landslide hazard zones: Autonomous Republic of Adjara (Keda, Khelvachauri, Khulo, Kobuleti, Shuakhevi), Guria (Chokhatauri, Lanchkhuti, Ozurgeti), Imereti (Baghdati, Chiatura, Kharagauli, Khoni, Kutaisi, Sachkhere, Samtredia, Terjola, Tkibuli, Tskaltubo, Vani, Zestaphoni), Kakheti (Akhmeta, Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo, Signagi, Telavi), Kvemo Kartli (Bolnisi, Dmanisi, Gardabani, Marneuli, Tetritskaro,Tsalka), Mtskheta-Mtianeti (Dusheti, Kazbegi, Mtskheta, Tianeti), Samegrelo-Zemo Svaneti (Chkhorotsku, Khobi, Martvili, Mestia, Senaki,Tsalenjikha, Zugdidi), Racha-Lechkhumi and Kvemo Svaneti

(Ambrolauri, Lentekhi, Oni, Tsageri), Samtskhe-Javakheti (Adigeni, Akhalkalaki, Akhaltsikhe, Aspindza, Borjomi), Shida Kartli (Gori, Kareli, Kaspi, Khashuri), Tbilisi.

The data of Department of Geology at Georgian National Environmental Agency about monthly sum of atmospheric precipitations for 62 meteorological stations are used [53]. Period of observation: 2015-2024 (10 years). Locations of meteorological stations in Fig. 1 is presented.

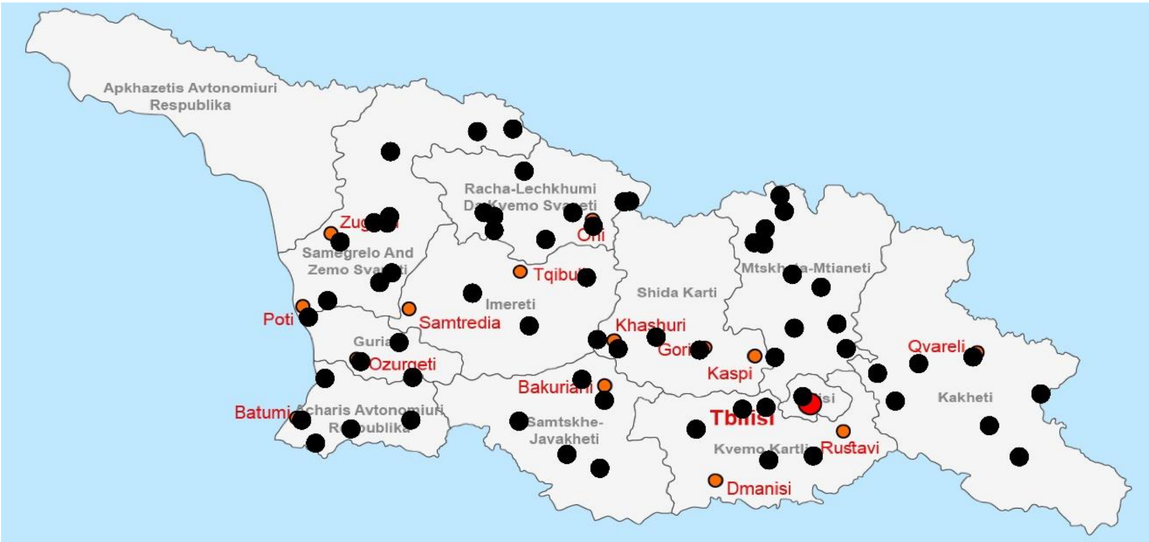

Fig. 1. Locations of meteorological stations.

Precipitation data from missing weather stations for some municipalities were compensated by data from the nearest weather stations, taking into account their representativeness [35].

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [60].

The following designations will be used below: Max - maximal values; Min - minimal values; Mean - average values; St Dev - standard deviation; R^2 – coefficient of determination; R – coefficient of linear correlation; R' - correlation index for nonlinear regression; α - the level of significance; Lat - north latitude, °N; Lon - east longitude, °E; H – altitude above sea level, m; P – precipitation, mm; P_{cold} – sum precipitation in cold period from October to March; P_{warm} – sum precipitation in warm period from April to September; P_{year} – annual sum of precipitation from January to December. In the text below, the dimensions of precipitation (mm) are often omitted.

The degree of correlation was determined in accordance with [60]: 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 ($0 \le R < 0.3$).

Results and discussion

Results in Table 1-4 and Fig. 2-8 are presented.

In Table 1 statistical characteristics of semi-annual and annual sum of atmospheric precipitation by 59 municipalities of Georgia in 2015-2024 is presented.

As follows from Table 1 P_{cold} values change from 139 (Gardabani) to 1589 (Kobuleti), P_{warm} – from 236 (Marneuli) to 1072 (Kobuleti) and P_{year} – from 383 (Gardabani) to 2662 (Kobuleti). In Fig. 2 as an example distribution of mean annual sum of atmospheric precipitation by municipalities of Georgia in 2015-2024 is presented.

Table 1. Statistical characteristics of semi-annual and annual sum of atmospheric precipitation by municipalities of Georgia in 2015-2024. $R_{min} = 0.25$, $\alpha = 0.05$

Variable	Lat	Lon	H, m	Cold	Warm	Year
Max	43.04	46.24	1747	1589	1072	2662
Min	41.36	41.67	7	139	236	383
Mean	42.01	43.50	556	569	523	1092
St Dev	0.39	1.30	439	397	200	577
	Correlation Matrix					
Lat	1	-0.39	-0.19	0.27	0.38	0.32
Lon	-0.39	1	0.39	-0.79	-0.66	-0.77
H	-0.19	0.39	1	-0.68	-0.56	-0.66
Cold	0.27	-0.79	-0.68	1	0.85	0.98
Warm	0.38	-0.66	-0.56	0.85	1	0.93
Year	0.32	-0.77	-0.66	0.98	0.93	1

There is a very high linear correlation between the values of P_{year}, P_{cold} and P_{warm} (Table 1, Fig. 3). The degree of correlation between the values of P_{warm} and P_{cold} is high. With increasing altitude in a linear approximation, there is a tendency for the average semi-annual and annual precipitation to decrease (moderate correlation). The values of the parameters under study in a linear approximation either do not depend (P_{cold}, negligible correlation) or depend weakly (P_{warm} and P_{year}, low positive correlation) on the latitude of the area. At the same time, there is a moderate negative correlation of P_{warm} and a high negative correlation of P_{year}, and P_{cold} with the longitude of the area (decreasing to the east).

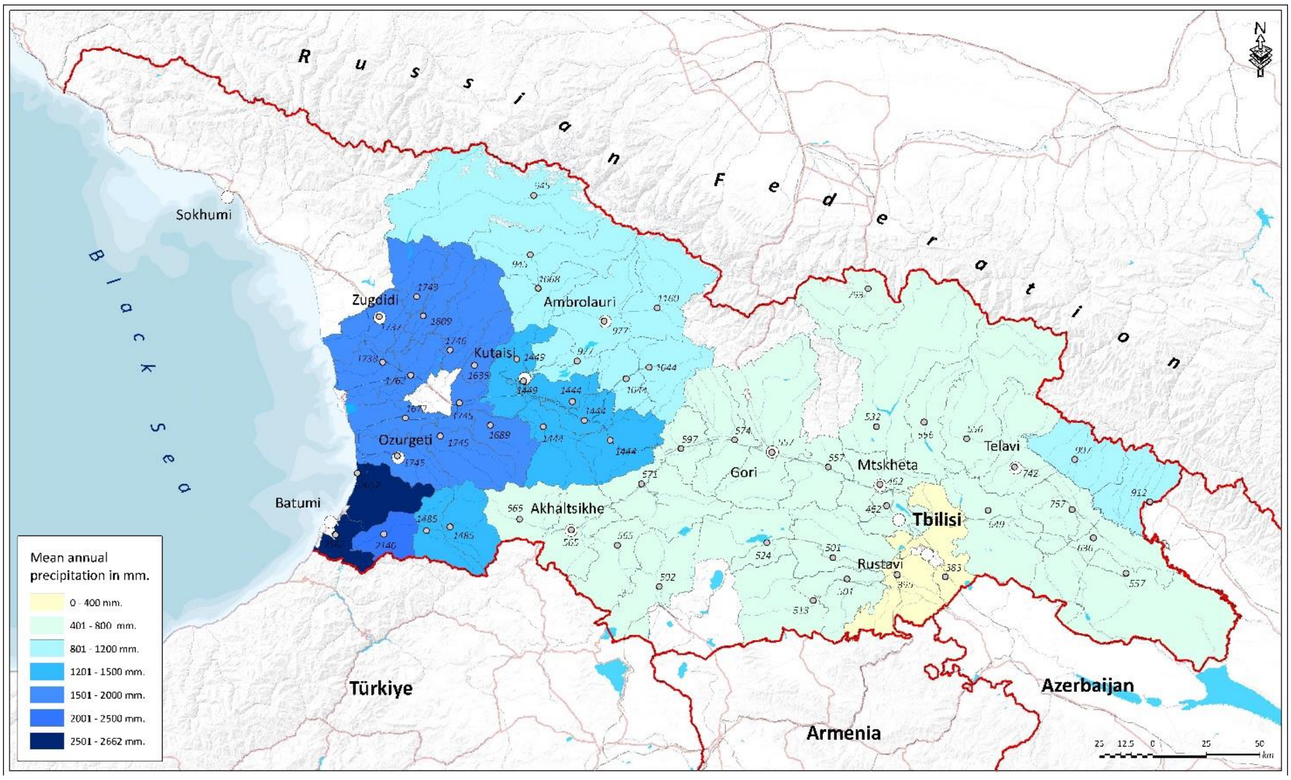

Fig. 2. Distribution of mean annual sum of atmospheric precipitation by municipalities of Georgia in 2015-2024.

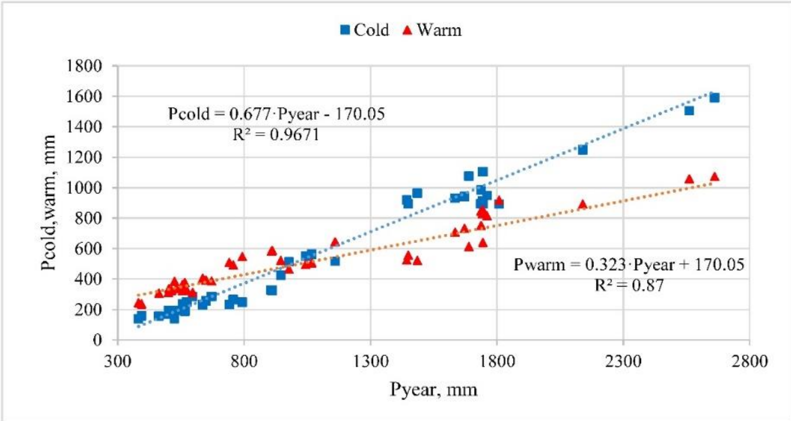

Fig. 3. Linear correlation and regression between semi-annual and annual sum of atmospheric precipitation by municipalities of Georgia in 2015-2024. $R \geq 0.93$, very high correlation.

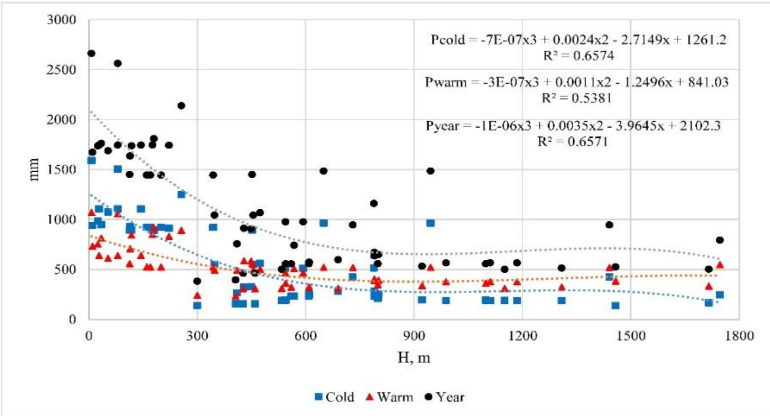

Fig. 4. Vertical distribution of semi-annual and annual atmospheric precipitation in Georgia, averaged over its municipalities in 2015-2024. $0.73 \leq R' \leq 0.81$, high correlation.

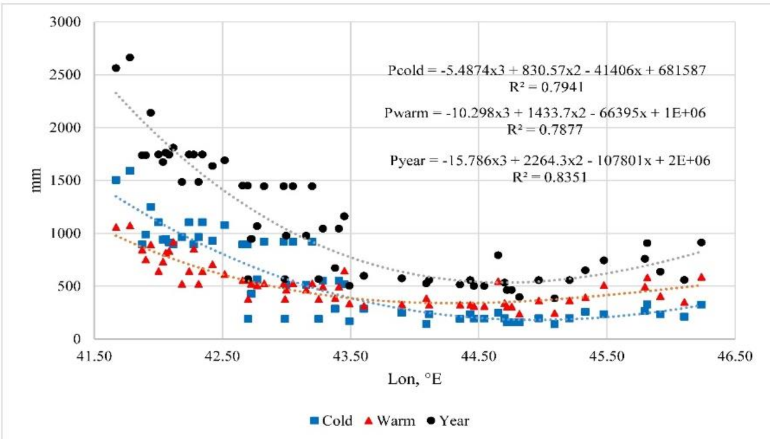

Fig. 5. Distribution by longitude of semi-annual and annual atmospheric precipitation in Georgia, averaged over its municipalities in 2015-2024. For P_{cold} and P_{warm} value of $R' = 0.89$, high correlation; for P_{year} value of $R' = 0.91$, very high correlation.

In reality, the dependence of the studied parameters on the altitude and longitude of the area is better described by third-degree polynomials (Fig. 4 and 5). In the first case, the correlation index R' is high, in the second – very high.

With a high level of reliability, relationship between the annual sum of atmospheric precipitation averaged by municipalities and the latitude and longitude of the area in Georgia can be represented by the following regression equation (the corresponding regression coefficients are presented in Table 2):

$$P_{year} = a+b/x1+c/x2+d/x1^2+e/x2^2+f/(x1*x2)+g/x1^3+h/x2^3+i/(x1*x2^2)+j/(x1^2*x2)$$

x1 – Lon °E, x2 – Lat °N, $R^2 = 0.8936$, R' = 0.95, very high correlation.

Table 2. Coefficients of the equation for the relationship between the annual sum of atmospheric precipitation averaged by municipalities and the latitude and longitude of the area in Georgia in 2015-2024.

Coefficient	a	b	c	d	e	f	g	h	i	j
Value	-3.79· E+07	9.69· E+08	3.85· E+09	-3.72· E+10	-1.55· E+11	-1.14· E+10	1.79· E+11	2.41· E+12	-7.86· E+11	1.07· E+12

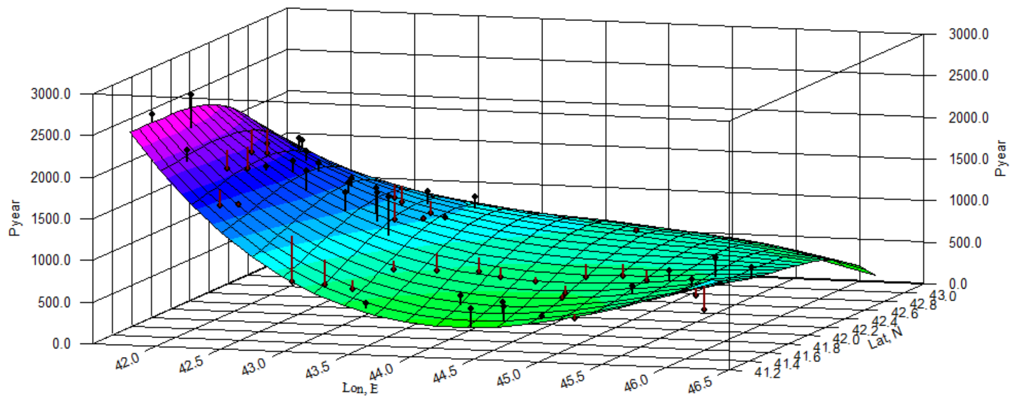

Fig. 6. Calculation model of distribution of annual sum of atmospheric precipitation in Georgia, averaged across its municipalities in 2015-2024.

In Fig. 6 calculation model of distribution of annual sum of atmospheric precipitation in Georgia, averaged across its municipalities, is presented, the actual data of which are given in Fig. 2.

In separated regions of Georgia changeability of semi-annual and annual sum of atmospheric precipitation is as follows (Table 3).

Table 3. Statistical characteristics of semi-annual and annual sum of atmospheric precipitation by separated region of Georgia in 2015-2024.

Variable	Lat	Lon	H, m	Cold	Warm	Year
Region	Autonomous Republic of Adjara (Adj)					
Max	41.85	42.31	946	1589	1072	2662
Min	41.59	41.67	7	963	522	1485
Mean	41.66	41.976	388	1254	813	2067
St Dev	0.11	0.27	399	293	275	566
Region	Guria (Gur)					
Max	42.09	42.24	144	1105	732	1745
Min	41.93	42	10	941	640	1672
Mean	42.01	42.09	78	1050	671	1721
St Dev	0.08	0.13	67	95	53	42
Region	Imereti (Im)					
Max	42.35	43.41	593	1105	706	1745
Min	42.02	42.34	28	512	465	977

Mean	42.21	42.87	253	849	552	1401
St Dev	0.12	0.35	181	200	69	253
Region	Kakheti (Kakh)					
Max	42.04	46.24	802	326	587	912
Min	41.47	45.21	410	194	348	556
Mean	41.78	45.74	599	255	460	715
St Dev	0.19	0.37	173	49	96	141
Region	Kvemo Kartli (KK)					
Max	41.6	45.09	1458	191	384	524
Min	41.36	44.09	300	139	236	383
Mean	41.48	44.56	860	168	302	470
St Dev	0.08	0.35	504	25	55	63
Region	Mtskheta-Mtianeti (MM)					
Max	42.67	44.97	1747	246	546	793
Min	41.85	44.65	460	156	306	462
Mean	42.18	44.76	1057	198	388	586
St Dev	0.35	0.14	533	37	108	144
Region	Samegrelo-Zemo Svaneti (S-ZS)					
Max	43.04	42.73	1441	986	917	1809
Min	42.27	41.87	25	425	520	945
Mean	42.52	42.15	314	850	790	1640
St Dev	0.26	0.29	503	191	129	307
Region	Racha-Lechkhumi and Kvemo Svaneti (R-L KS)					
Max	42.79	43.45	789	562	645	1160
Min	42.52	42.72	474	425	465	945
Mean	42.64	43.02	635	504	534	1038
St Dev	0.12	0.34	150	57	78	97
Region	Samtskhe-Javakheti (S-J)					
Max	41.84	43.49	1716	285	386	671
Min	41.41	42.7	790	167	335	502
Mean	41.63	43.16	1158	204	370	574
St Dev	0.16	0.32	346	46	20	61
Region	Shida Kartli (Sh K)					
Max	42.03	44.43	690	284	325	597
Min	41.92	43.6	560	234	312	557
Mean	41.98	44.01	617	250	321	571
St Dev	0.05	0.35	54	24	6	19
Region	Tbilisi (Tb)					
Mean	41.76	44.76	427	156	306	462

Adj: Cold period – from 963 (Khulo, Shuakhevi) to 1589 (Kobuleti), average value – 1254. Warm period – from 522 (Khulo, Shuakhevi) to 1072 (Kobuleti), average value – 1072. Year – from1485 (Khulo, Shuakhevi) to 2262 (Kobuleti), average value – 2067.

Gur: Cold period – from 941 (Lanchkhuti) to 1105 (Chokhatauri, Ozurgeti), average value – 1050. Warm period – from 640 (Chokhatauri, Ozurgeti) to 732 (Lanchkhuti), average value – 671. Year – from 1672 (Lanchkhuti) to 1745 (Chokhatauri, Ozurgeti), average value – 1721.

Im: Cold period – from 512 (Tkibuli) to 1105 (Samtredia), average value – 849. Warm period – from 465 ((Tkibuli) to 706 (Khoni), average value – 552. Year – from 977 (Tkibuli) to 1745 (Samtredia), average value – 1401.

Kakh: Cold period – from 194 (Akhmeta) to 326 (Kvareli), average value – 255. Warm period – from 348 (Dedoplistskaro) to 587 (Lagodekhi), average value – 460. Year – from 556 (Akhmeta) to 912 (Lagodekhi), average value – 715.

KK: Cold period – from 139 (Gardabani) to 191 (Bolnisi, Tetritskaro), average value – 168. Warm period – from 236 (Marneuli) to 384 (Tsalka), average value – 302. Year – from 383 (Gardabani) to 524 (Tsalka), average value – 470.

MM: Cold period – from 156 (Mtskheta) to 246 (Kazbegi), average value – 198. Warm period – from 306 (Mtskheta) to 546 (Kazbegi), average value – 388. Year – from 462 (Mtskheta) to 793 (Kazbegi), average value – 586.

(S-ZS: Cold period – from 425 (Mestia) to 986 (Khobi), average value – 850. Warm period – from 520 (Mestia) to 917 (Chkhorotsku), average value – 790. Year – from 945 (Mestia) to 1809 (Chkhorotsku), average value – 1640.

R-L KS: Cold period – from 425 (Lentekhi) to 562 (Tsageri), average value – 504. Warm period – from 465 (Ambrolauri) to 645 (Oni), average value – 534. Year – from 945 (Lentekhi) to 1160 (Oni), average value – 1038.

S-J: Cold period – from 167 (Akhalkalaki) to 285 (Borjomi), average value – 204. Warm period – from 335 (Akhalkalaki) to 386 (Borjomi), average value – 370. Year – from 502 (Akhalkalaki) to 671 (Borjomi), average value – 574.

Sh K: Cold period – from 234 (Gori, Kaspi) to 284 (Khashuri), average value – 250. Warm period – from 312 (Khashuri) to 325 (Kareli), average value – 321. Year – from 557 (Gori, Kaspi) to 597 (Khashuri), average value – 571.

Tb: Cold period, average value – 156. Warm period, average value – 306. Year, average value – 462.

Table 4. Statistical characteristics of semi-annual and annual sum of atmospheric precipitation averaged by regions of Georgia in 2015-2024. $R_{min} = 0.60$, $\alpha = 0.05$

Variable	Lat	Lon	H, m	Cold	Warm	Year
Max	42.64	45.74	1158	1254	813	2067
Min	41.48	41.98	78	156	306	462
Mean	41.99	43.55	581	522	501	1022
St Dev	0.37	1.28	337	405	188	584
	Correlation Matrix					
Lat	1	-0.34	-0.28	0.25	0.38	0.30
Lon	-0.34	1	0.49	-0.84	-0.78	-0.84
H, m	-0.28	0.49	1	-0.73	-0.63	-0.71
Cold	0.25	-0.84	-0.73	1	0.93	0.99
Warm	0.38	-0.78	-0.63	0.93	1	0.97
Year	0.30	-0.84	-0.71	0.99	0.97	1

Changeability of semi-annual and annual sum of atmospheric precipitation averaged by regions of Georgia is as follows (Table 4).

Cold period – from 156 (Tb) to 1254 (Adj), average value – 522. Warm period – from 306 (Tb) to 813 (Adj), average value – 501. Year – from 462 (Tb) to 2067 (Adj), average value – 1022.

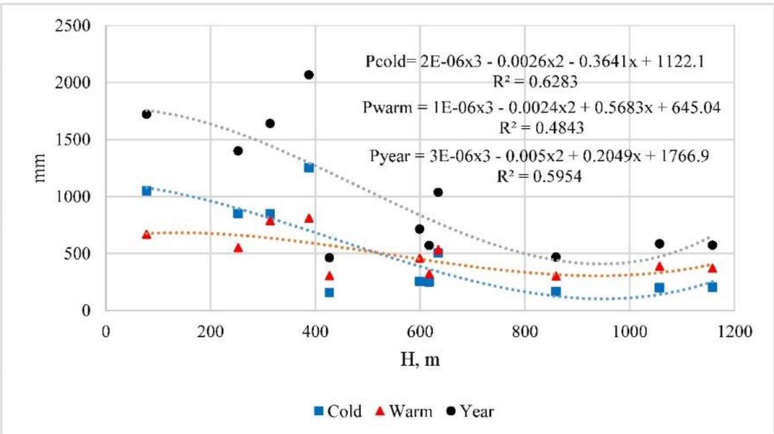

Fig. 7. Vertical distribution of semi-annual and annual atmospheric precipitation in Georgia, averaged over its regions in 2015-2024. $0.70 \le R' \le 0.79$, high correlation.

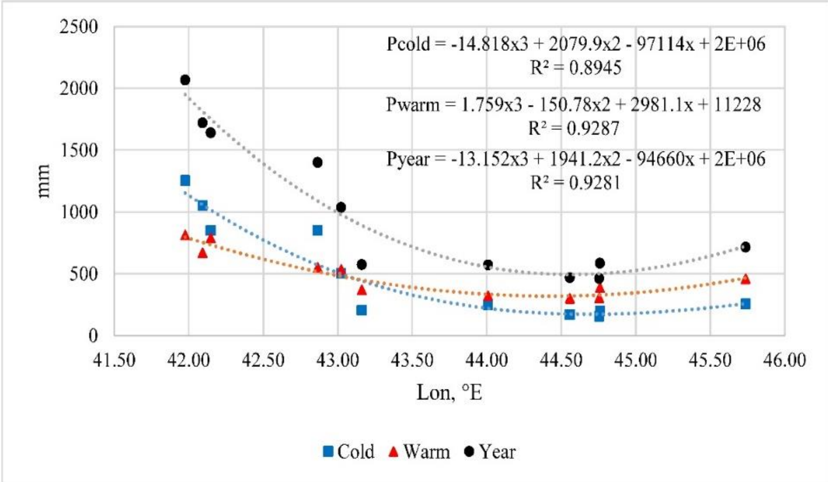

Fig. 8. Distribution by longitude of semi-annual and annual atmospheric precipitation in Georgia, averaged over its regions in 2015-2024. R' ≥ 0.95, very high correlation.

Both in the cases with municipalities (Fig. 4 and 5) and according to the data for the regions of Georgia (Fig. 7 and 8, data from Table 3), the dependence of the average values of semi-annual and annual precipitation sum on the altitude and longitude of the area has the form of third-degree polynomials. As in the previous cases the correlation index R' is high for connection of parameters under study with H, and very high - or connection with E.

Conclusion

A detailed statistical analysis of data from 62 meteorological stations in Georgia, located in 59 municipalities (11 regions) of Georgia with dangerous landslide zones, on semi-annual and annual sum of atmospheric precipitation was conducted.

In the near future, it is planned to use the results of this work for a more detailed study of the connections between precipitation and the activation of landslide processes on a climatic time scale.

Acknowledgments

This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG), Grant number FR-23-5466, “Machine Learning Approach to the Landslide Activation Prediction in Georgia”.

References

[1] Brocca L. et al. Soil as a natural rain gauge: Estimating global rainfall from satellite soil moisture data. Journal of Geophysical Research: Atmospheres, 119, 2014, pp. 5128–5141.

[2] Massari C., Crow, W., Brocca, L. An assessment of the performance of global rainfall estimates without ground-based observations. Hydrology and earth system sciences, 21, 2017, pp. 4347–4361.

[3] Sun Q. et al. A review of global precipitation data sets: Data sources, estimation, and intercomparisons. Reviews of Geophysics, 56, 2018, pp. 79–107.

[4] Brocca L. et al. SM2RAIN–ASCAT (2007–2018): global daily satellite rainfall data from ASCAT soil moisture observations. Earth System Science Data, 11, 2019, pp. 1583–1601.

[5] Bartolini G., Grifoni D., Magno R., Torrigiani T., Gozzini B. Changes in temporal distribution of precipitation in a Mediterranean area (Tuscany, Italy) 1955–2013. Int. Journal of Climatology, 38, 2018, pp. 1366–1374. https:// doi.org/10.1002/joc.5251

[6] Yaman B., Ertugrul M. Change-point detection and trend analysis in monthly, seasonal and annual air temperature and precipitation series in Bartın province in the western Black Sea region of Turkey. Geology, Geophysics and Environment, 46, 223, 2020. https://doi.org/10.7494/geol.2020.46.3.223

[7] Bouklikha A., Habi M., Elouissi A., Hamoudi,S. Annual, seasonal and monthly rainfall trend analysis in the Tafna watershed, Algeria. Applied Water Science, 11, 77, 2021. https://doi.org/10.1007/s13201-021-01404-6

[8] Kharyutkina E, Loginov S, Martynova Y, Sudakov I. Time series analysis of atmospheric precipitation characteristics in Western Siberia for 1979–2018 across different datasets. Atmosphere, 13(2), 2022 Jan 24, 189.

[9] Mosaffa H., Filippucci P., Massari C., Ciabatta, Brocca L. SM2RAIN-Climate, a monthly global long-term rainfall dataset for climatological studies. Sci Data, 10, 2023, 749. https://doi.org/10.1038/s41597-023-02654-6

[10] Gonzalez-Hidalgo J.C., Beguería S., Peña-Angulo D., Trullenque-Blanco V. MOPREDAS_century database and precipitation trends in mainland Spain, 1916–2020. Int. Journal of Climatology, 43, 2023, pp. 3828–3840. https://doi.org/10.1002/joc.8060

[11] Benziane S. Survey: Rainfall prediction precipitation, review of statistical methods. WSEAS Transactions on Systems, 23, 2024, pp. 47-59.

[12] Gonzalez-Hidalgo J.C., Trullenque-Blanco V., Beguería S., Peña-Angulo D. Seasonal precipitation changes in the western Mediterranean Basin: The case of the Spanish mainland, 1916–2015. Int. Journal of Climatology, 44(5), 2024, pp. 1800-1815.

[13] Syam N. S. S., Sunil A., Pichuka,S., Mandal A. Assessment of climate change impacts on the precipitation and temperature: A case study on Krishna River Basin, India. Russian Meteorology and Hydrology, 49(1), 2024, pp. 62-70.

[14] Alibegova D., Elizbarashvili E. Statisticheskaia struqtura atmospernikh osadkov v gornikh raionakh. Leningrad, 1980, 136 p., (in Russian).

[15] Opasnyye gidrometeorologicheskiye yavleniya na Kavkaze. Pod red. Svanidze G.G. i Tsutskiridze Ya.A., L., Gidrometeoizdat, 1980, 288 s., (in Russian).

[16] Tavartqiladze K. Saqartveloshi naleqebis ganacilebis statistikuri struqtura. Hidrometeorologiis institutis Sromebi, "Mecniereba", N 105, 2002, 117 p., (in Georgian).

[17] Tavartkiladze K., Begalishvili N., Kharchilava J., Mumladze D., Amiranashvili A., Vachnadze J., Shengelia I., Amiranashvili V. Contemporary climate change in georgia. Regime of Some Climate Parameters and their Variability. Monograph, ISBN 99928-885-4-7, Tbilisi, 2006, 177 p., (in Georgian).

[18] Kartvelishvili L., Tatishvili M., Amiranashvili A., Megrelidze L., Kutaladze N. Weather, Climate and their Change Regularities for the Conditions of Georgia. Monograph, publishing house "UNIVERSAL", ISBN: 978-9941-33-465-8, Tbilisi 2023, 406 p., https://doi.org/10.52340/mng.9789941334658

[19] Khvedelidze Z., Amiranashvili A., Dolidze J., Chitaladze D., Pavlenishvili N. Statistical structure of diurnal precipitation distribution on the territory of Eastern Georgia. Proc. of I. Javakhishvili Tbilisi State University, Physics, N 357, ISSN 1512-1461, Tbilisi University Press, Tbilisi, 2004, pp. 79-87.

[20] Amiranashvili A.G. Special features of changeability of daily sum of precipitation in Tbilisi in 1957-2006. Journal of the Georgian Geophysical Society, Issue B. Physics of Atmosphere, Ocean and Space Plasma, v.18B, Tbilisi, 2015, pp.81-91.

[21] 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;

[22] Bliadze T., Gvasalia G., Kirkitadze D., Mekoshkishvili N. Changeability of the atmospheric precipitations regime in Kakheti in 1956-2015. Int. Sc. Conf. "Natural Disasters in Georgia: Monitoring, Prevention, Mitigation". Proceedings, ISBN 978-9941-13-899-7, Publish House of Iv. Javakhishvili Tbilisi State University, December 12-14, Tbilisi, 2019, pp. 74-77.

[23] Amiranashvili A. Changeability of air temperature and atmospheric precipitations in Tbilisi for 175 Years. Int. Sc. Conf. "Natural Disasters in Georgia: Monitoring, Prevention, Mitigation". Proceedings, ISBN 978-9941-13-899-7, Publish House of Iv. Javakhishvili Tbilisi State University, December 12-14, Tbilisi, 2019, pp. 86-90.

[24] Bolashvili N., Chikhladze V., Kartvelishvili L., Tatishvili M. Variability of atmospheric precipitation in Tbilisi in 1844-2023. Int. Sc. Conf. “Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country”, Proceedings, ISBN 978-9941-36-272-9, publish house of Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia, October 17-19, 2024, pp. 150 – 154. http://dspace.gela.org.ge/bitstream/123456789/10620/1/38_MM-180.pdf

[25] Amiranashvili A.G., Revishvili A.A., Khazaradze K.R., Japaridze N.D. Connection of Holiday Climate Index with public health (on example of Tbilisi and Kakheti region, Georgia). Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 63-76.

[26] Amiranashvili A.G., Kartvelishvili L.G., Kutaladze N.B., Megrelidze L.D., Tatishvili M.R. Changeability of the meteorological parameters associated with Holiday Climate Index in different mountainous regions of Georgia in 1956-2015. Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(2), 2021, pp. 78-91. DOI: https://doi.org/10.48614/ggs2420213326

[27] 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

[28] Tsitsagi M., Gulashvili Z., Bolashvili N., Tatishvili M., Suknidze N. Relationship between Normalized 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

[29] Tatishvili M., Kapanadze N., Mkurnalidze I., Palavandishvili A. Drought evaluation in Georgia using SPI and SPEI Indices. Int. Sc. Conf. “Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country”, Proceedings, ISBN 978-9941-36-272-9, Publish House of Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia, October 17-19, 2024, pp. 96 – 100.

[30] Beglarashvili N., Janelidze I., Pipia M., Varamashvili N. Heavy rainfall, floods and floodings in Kakheti (Georgia) in 2014-2018. Int. Sc. Conf. „Modern Problems of Ecology“, Proc., ISSN 1512-1976, v. 7, Tbilisi-Telavi, Georgia, 26-28 September, 2020, pp. 180-184.

[31] Beglarashvili N., Jamrishvili N., Janelidze I., Pipia M., Tavidashvili Kh. Analysis of strong precipitation in Tbilisi on August 29, 2023. Int. Sc. Conf. "Geophysical Processes in the Earth and its Envelopes". Proceedings, ISBN 978-9941-36-147-0, Publish House of Iv. Javakhishvili Tbilisi State University, November 16-17, 2023, pp. 143-146. http://www.dspace.gela.org.ge/handle/123456789/10421

[32] Varazanashvili O., Tsereteli N., Amiranashvili A., Tsereteli E., Elizbarashvili E., Dolidze J., Qaldani L., Saluqvadze M., Adamia Sh., Arevadze N., Gventcadze A. Vulnerability, hazards and multiple risk assessment for Georgia. Natural Hazards, Vol. 64, Number 3, 2012, pp. 2021-2056. DOI: 10.1007/s11069-012-0374-3, http://www.springerlink.com/content/9311p18582143662/fulltext.pdf.

[33] Elizbarashvili E.Sh., Elizbarashvili M.E. Stikhiynyye meteorologicheskiye yavleniya na territorii Gruzii. Tbilisi, Zeon, 2012, 104 s., (in Russian).

[34] Tatishvili M., Elizbarashvili E., Meskhia R., Elizbarashvili Sh. Natural hydrometeorological disasters, their causes and prevention measures. The Macrotheme Review. A Multidisciplinary Journal of Global Macro Trends. A Macrotheme Capital Management. LLC Academic Publication, ISSN 1848-4735, v. 2, iss.1, Winter 2013 (January)., France, pp. 148-154.

[35] Amiranashvili A., Chelidze T., Svanadze D., Tsamalashvili T., Tvauri G. On the representativeness of data from meteorological stations in Georgia for annual and semi-annual sum of atmospheric precipitation around of these stations. Int. Sc. Conf. „Natural Disasters in the 21st Century: Monitoring, Prevention, Mitigation“. Proceedings, ISBN 978-9941-491-52-8, Tbilisi, Georgia, December 20-22, 2021. Publish house of Iv. Javakhishvili Tbilisi State University, Tbilisi, 2021, pp. 79 - 83. http://openlibrary.ge/bitstream/123456789/9566/1/20_Conf_ND_2021.pdf

[36] 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

[37] Amiranashvili A., Chelidze T., Svanadze D., Tsamalashvili T., Tvauri G. Comparison of data from ground-based and satellite measurements of the monthly sum of atmospheric precipitation on the example of Tbilisi city in 2001-2020. 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. 154-158. http://openlibrary.ge/bitstream/123456789/10251/1/37_YSC_2022.pdf

[38] Amiranashvili A., Chelidze T., Svanadze D., Tsamalashvili T., Varamashvili N. Comparison of satellite and ground-based data on semi-annual and annual sum of atmospheric precipitation for 26 points in Georgia in 2001-2020. Int. Sc. Conf. "Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country", Proceedings, ISBN 978-9941-36-272-9, Publish House of Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia, October 17-19, 2024, pp. 159 – 163. http://www.openlibrary.ge/bitstream/123456789/10618/1/40_MM-180.pdf

[39] Beglarashvili N., Jamrishvili N., Janelidze I., Pipia M., Tavidashvili Kh. Some results of analysis of heavy precipitation in Tbilisi on July 7, 2024 based on ground-level and satellite measurements. Int. Sc. Conf. "Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country", Proceedings, ISBN 978-9941-36-272-9, Publish house of Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia, October 17-19, 2024, pp. 164 – 167. http://dspace.gela.org.ge/bitstream/123456789/10617/1/41_MM-180.pdf

[40] Tsitelashvili N., Biggs T., Ye Mu, Trapaidze V. Regional precipitation regimes and evaluation of national precipitation datasets against satellite-based precipitation estimates, Republic of Georgia. Journal of Hydrometheorology, Vol. 25, Iss. 4, 2024, pp. 591–600. https://doi.org/10.1175/JHM-D-23-0116.1

[41] Elizbarashvili M., Amiranashvili A., Elizbarashvili E., Mikuchadze G., Khuntselia T., Chikhradze N. Comparison of RegCM4.7.1 Simulation with the station observation data of Georgia,1985–2008. Atmosphere, ISSN: 2073-4433, 15, 369, 2024, 19 pp. https://doi.org/10.3390/atmos15030369

[42] Elizbarashvili M., Elizbarashvili E., Kalmár T., Khuntselia T., Chikhradze N. Assessing regional climate model RegCM4.7.1: Insights from simulations in Georgia. Geomate Journal, 27(121), 2024 Sep 30, pp. 41-55.

[43] Aliyev V., Pkhovelishvili M., Archvadze N., Gasitashvili Z. Hybrid risk review. Int. Journal of Sustainability and Risk Control, Baku, Azerbaijan, Vol.1, No 1(1), June 2025, pp. 12-23.

[44] Amiranashvili A., Chelidze T., Dalakishvili L., Svanadze D., Tsamalashvili T., Tvauri G. Preliminary results of a study of the relationship between the monthly mean sum of atmospheric precipitation and landslide cases in Georgia. Journal of the Georgian Geophysical Society, ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 23(2), 2020, pp. 37 – 41.

[45] Amiranashvili A., Chelidze T., Dalakishvili L., Svanadze D., Tsamalashvili T., Tvauri G. Preliminary results of a study of the relationship between the variability of the mean annual sum of atmospheric precipitation and landslide processes in Georgia. Int. Sc. Conf. „Modern Problems of Ecology", Proc., ISSN 1512-1976, v. 7, Tbilisi-Telavi, Georgia, 26-28 September, 2020, pp. 202-206.

[46] Chelidze, T., Tsamalashvili, T., Fandoeva, M. Mass-movement stationary hazard maps of Georgia including precipitation triggering effect: fuzzy logic approach. Bull. Georg. Nat. Acad. Sci., vol. 16, no. 2, 56-63, 2022, http://science.org.ge/bnas/t16-n2/07_Chelidze_Geophysics.pdf

[47] Amiranashvili A., Chelidze T., Svanadze D., Tsamalashvili T., Tvauri G. Some results of a study of the relationship between the mean annual sum of atmospheric precipitation and re-activated and new landslide cases in Georgia taking into account of climate change. Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 25(2), 2022, pp. 38–48. https://openjournals.ge/index.php/GGS/article/view/5959, DOI: https://doi.org/10.48614/ggs2520225959

[48] Chelidze T., Amiranashvili A., Svanadze D., Tsamalashvili T., Tvauri G. Terrestrial and satellite-based assessment of rainfall triggered landslides activity in Georgia, Caucasus. Bull. Georg. Nat. Acad. Sci., vol. 17, no. 2, 71-77, 2023, http://science.org.ge/bnas/vol-17-2.html

[49] Amiranashvili A., Chelidze T., Svanadze D., Tsamalashvili T., Tvauri G. Study of the relationship between the mean annual sum of atmospheric precipitation and re-activated and new mudflow cases in Georgia. Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 26(1), 2023, pp. 19–29. https://ggs.openjournals.ge/index.php/GGS/article/view/6958; DOI: https://doi.org/10.48614/ggs2620236958

[50] Amiranashvili A., Chelidze T., Svanadze D., Tsamalashvili T., Tvauri G. Abnormal precipitation before the landslide in Akhaldaba (A Suburb of Tbilisi, Georgia) on June 13, 2015 according to radar measurements. Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 26(1), 2023, pp. 30–41.

[51] Amiranashvili A., Brocca L., Chelidze T., Svanadze D., Tsamalashvili T., Varamashvili N. Analysis of the precipitation regime that triggered the landslide in Nergeeti (Imereti, Georgia) on February 7, 2024. Int. Sc. Conf. “Complex Geophysical Monitoring in Georgia: History, Modern Problems, Promoting Sustainable Development of the Country”, Proceedings, ISBN 978-9941-36-272-9, Publish house of Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia, October 17-19, 2024, pp. 155 – 158. http://dspace.gela.org.ge/bitstream/123456789/10619/1/39_MM-180.pdf

[52] Varazanashvili O., Gaprindashvili G., Elizbarashvili E., Basilashvili, Ts., Amiranashvili A., Fuchs S. The First Natural Hazard Event Database for the Republic of Georgia (GeNHs). Catalog, 2023, 270 p. http://dspace.gela.org.ge/handle/123456789/10369; DOI: 10.13140/RG.2.2.12474.57286

[53] Geological bulletins. 2016-2025, (in Georgian). https://nea.gov.ge/c/Departments/Geology

[54] Amiranashvili A., Basilashvili Ts., Elizbarashvili E., Varazanashvili O. Catastrophic floods in the vicinity of Tbilisi. Transactions IHM, GTU, ISSN: 1512-0902, vol.133, 2023, pp. 56-61, (in Georgian), doi.org/10.36073/1512-0902-2023-133-56-61; http://openlibrary.ge/bitstream/123456789/10337/1/133-11.pdf; doi.org/10.36073/1512-0902-2023-133-56-61

[55] Amiranashvili A., Elizbarashvili E., Gaprindashvili G., Varazanashvili O., Fuchs S. Assessment of the long-term risk of dangerous hurricanes on the territory of Georgia using data from 1961 to 2022. Reliability: Theory and Applications, ISSN 1932-2321, Special Issue № 6 (81), Part-2, Vol. 19, 2024, pp. 508 - 514. https://doi.org/10.24412/1932-2321-2024-681-508-514

[56] Amiranashvili A., Elizbarashvili E., Gaprindashvili G., Varazanashvili O., Fuchs S. Statistical analysis of parameterized landslide data in Georgia from 1900 to 2022. Reliability: Theory and Applications, ISSN 1932-2321, Special Issue № 6 (81), Part-2, Vol. 19, 2024, pp. 812 - 818. https://doi.org/10.24412/1932-2321-2024-681-812-818

[57] Pipia M., Amiranashvili A., Elizbarashvili E., Varazanashvili O., Beglarashvili N., Jamrishvili N. Variability in the number of days with hail in the warm half of the year on the territory of Georgia in 1941-2021. Reliability: Theory and Applications, ISSN 1932-2321, Special Issue № 6 (81), Part-2, Vol. 19, 2024, pp. 552 - 559. https://doi.org/10.24412/1932-2321-2024-681-552-559

[58] Pipia M.G., Amiranashvili A.G., Elizbarashvili E. Sh., Beglarashvili N.G., Pipia G.G., Jamrishvili N.K., Varazanashvili O. Sh. Degree and areas of damage caused by hail in the territory of Kakheti region (Georgia). Journal of International Scientiíc Publications: Agriculture & Food, ISSN 1314-8591, vol. 12, 2024, pp. 54-60. https://doi.org/10.62991/AF1996546926

[59] Pipia M.G., Amiranashvili A.G., Chikhladze V.A., Elizbarashvili E. Sh., Pipia G.G., Beglarashvili N.G., Varazanashvili O.Sh. Distribution of hailstorm areas in Kakheti region (Georgia) According to the diameter of hailstones in the clouds. Journal of International Scientiíc Publications: Ecology & Safety, ISSN 1314-7234, vol. 18, 2024, pp.103-108. https://doi.org/10.62991/ES1996566836

[60] 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.

ატმოსფერული ნალექების წლიური და ნახევარწლიური ჯამის სტატისტიკური ანალიზი საქართველოს 59 მეწყრული საშიშროების ზონების მქონე მუნიციპალიტეტისთვის (11 რეგიონი) 2015 - 2024 წწ.

ა. ამირანაშვილი, ლ. ბროკა, თ. ჭელიძე,
დ. სვანაძე, თ. წამალაშვილი, ნ. ვარამაშვილი

რეზიუმე

სტატიაში წარმოდგენილია საქართველოს იმ 62 მეტეოროლოგიური სადგურიდან ატმოსფერული ნალექების ჯამური წლიური და ნახევარწლიური მონაცემების სტატისტიკური ანალიზის შედეგები, რომლებიც განლაგებულია 59 მუნიციპალიტეტის (11 რეგიონის) ტერიტორიებზე, სადაც საშიში მეწყრული ზონები არსებობს. დაკვირვების პერიოდია 2015 წლიდან 2024 წლამდე. კერძოდ, მიღებული იქნა მუნიციპალიტეტების ტერიტორიებზე საშუალოდ გათვლილი ატმოსფერული ნალექების წლიური რაოდენობების განაწილების ემპირიული (რუკა) და გამოთვლითი მოდელები; შესწავლილი იქნა მუნიციპალიტეტებისა და რეგიონების ტერიტორიებზე საშუალოდ გათვლილი ატმოსფერული ნალექების ნახევარწლიური და წლიური რაოდენობების დამოკიდებულებები ტერიტორიის სიმაღლესთან, გრძედთან და ა.შ. მომავალში იგეგმება ამ ნაშრომის შედეგების გამოყენება ნალექებსა და მეწყრული პროცესების გააქტიურებას შორის კავშირის უფრო დეტალური შესწავლისთვის კლიმატური დროის მასშტაბში.

საკვანძო სიტყვები: ნალექი, კორელაციური და რეგრესიული ანალიზი, სტიქიური უბედურებები, მეწყერები.

Статистический анализ данных о годовых и полугодовых суммах атмосферных осадков для 59 муниципалитетов (11 регионов) Грузии с опасными оползневыми зонами с 2015 по 2024 гг.

**А. Амиранашвили, Л. Брокка, Т. Челидзе,
Д. Сванадзе, Т. Цамалашвили, Н. Варамашвили**

Резюме

Представлены результаты статистического анализа данных 62 метеорологических станций Грузии, расположенных на территориях 59 муниципалитетов (11 регионов) Грузии с опасными оползневыми зонами о полугодовых и годовых суммах атмосферных осадков. Период наблюдений – с 2015 по 2024 годы. В частности, получены эмпирическая (карта) и расчетная модели распределения осредненных по территориям муниципалитетов годовых сумм атмосферных осадков; изучены связи осредненных по территориям муниципалитетов и регионов значений полугодовых и годовых сумм атмосферных осадков с высотой и долготой местности и др.
В дальнейшем предусмотрено использовать результаты данной работы для более детального изучения связи между осадками и активизацией оползневых процессов в климатическом масштабе времени.

Ключевые слова: атмосферные осадки, корреляционно-регрессионный анализ, природные катастрофы, оползни.