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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

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ABSTRACT

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. 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.

Key words: *atmospheric precipitation, landslides, climate change.*

Introduction

Landslides are one type of disaster. Landslide processes are widespread almost everywhere and are dangerous due to damage, often accompanied by human casualties [1,2]. This problem is also very relevant for Georgia, where the number of landslides included in the cadastre reaches 7000 [3]. Therefore, special attention has always been paid to the study of landslide processes in this area [4–10].

Landslide phenomena depend on many separate and complex processes, in particular, on atmospheric precipitation [3,11,12]. At the same time, the time scale of the influence of atmospheric precipitation on the provocation of landslides has a wide range - from several tens of minutes to several days, months and years (climatic time scale). Thus, in [13], it was found that in Georgia, with an increase in the annual amount of atmospheric precipitation, there is a tendency for an increase in the number of landslides in accordance with the second degree of the polynomial. In another work [14], in particular, it was found that with an increase in the monthly amount of precipitation, a linear trend of an increase in the number of landslides is observed.

This work is a continuation of previous studies [13,14]. Below are the results of a study of the relationship between the average annual precipitation (Pa) for 21 meteorological stations and the number of re-activated and new landslides (LS) in Georgia, and an assessment of the LS values until 2045 using predictive data on Pa.

Study Area, Materials and Methods

Study Area – Georgia. Data from the Environmental Agency of Georgia on the annual amount of atmospheric precipitation for 21 meteorological stations of Georgia located in areas with landslides (fig. 1) and data on re-activated and new landslides cases (fig. 2) are used. Period of observation: for atmospheric precipitation from 1936 to 2020, for re-activated and new landslides cases from 1996 to 2018.

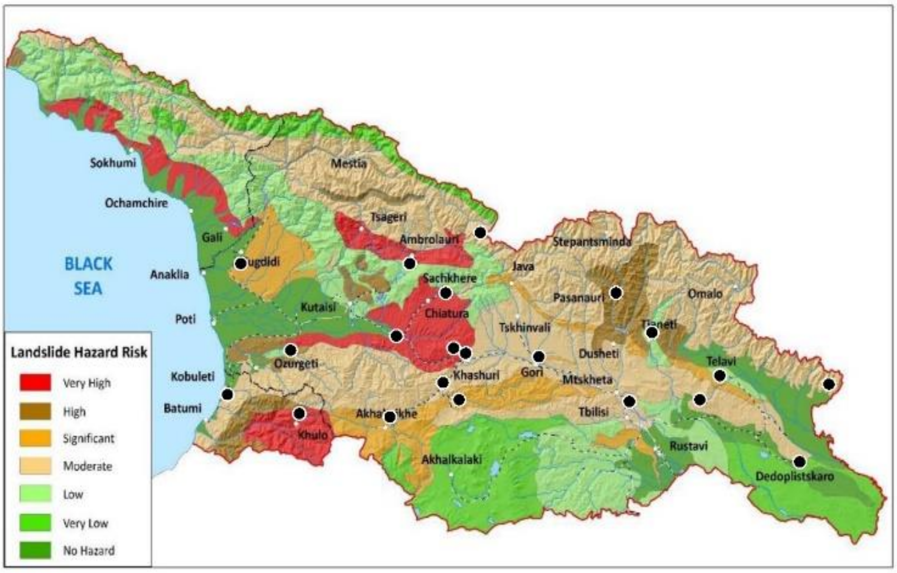

Fig 1. Location of 21 meteorological stations on the landslide risk zones map of Georgia by probability and damage.

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

The following designations will be used below: Mean – average values; Max - maximal values; Min – minimal values; Range – Max-Min; St Dev - standard deviation; St Err - standard error; Cv – coefficient of variation = 100·St Dev/Mean, %; Conf. Lev. - confidence level of the mean; Low and Upp – lower and upper levels of the confidence interval of the mean; R – coefficient of linear correlation; CR - coefficient of cross correlation; α - the level of significance; P - annual sum of atmospheric precipitation for separated meteorological station; Pa - mean annual sum of atmospheric precipitation for 21 meteorological stations; LS - re-activated and new landslides cases. Difference between mean annual sum of atmospheric precipitation in two periods of time was determined with the use of Student's criterion. The forecast of P_a using the AAA version of the Exponential Smoothing (ETS) algorithm was carried out [16]. Programs Excel 16 and Mesosaur for calculation were used.

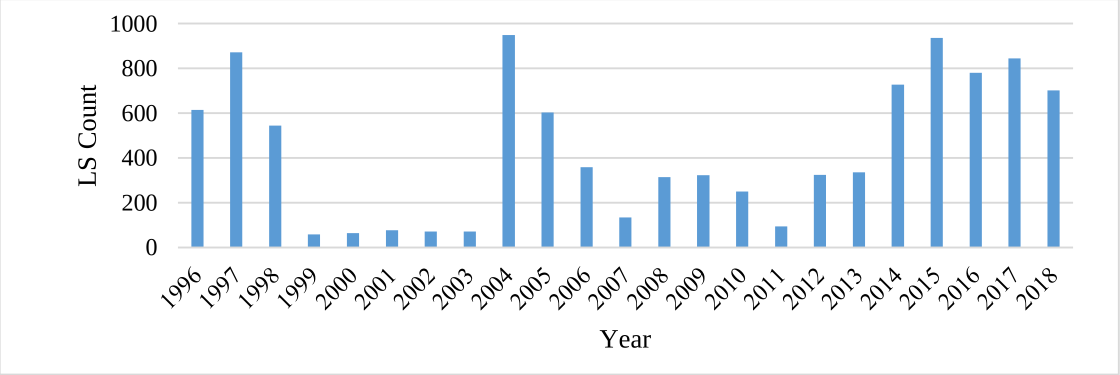

Fig 2. Changeability of re-activated and new landslides cases in Georgia from 1996 to 2018.

Results and Discussions

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 below in Table 1-3 and Fig. 3-8.

Table 1. Statistical characteristics of LS cases in Georgia in 1996-2018.

Parameter	Mean	Max	Min	Range	St Err	St Dev	Cv, %	Conf. Lev. , 95.0%
LS	437	949	58	891	66	316	72.2	136

Table 1 presents the statistical characteristics of LS cases in Georgia in 1996-2018. On average, 437 cases of LS were recorded per year with a range of changes from 58 to 949 cases. Significant variations in the amount of LS were observed in the specified time period (Cv = 72.2%, Conf. Lev. = 136).

Table 2 presents the statistical characteristics of the annual sum of atmospheric precipitations for 21 meteorological stations and the average annual sum precipitation for all these stations in 1936-2020.

Table 2. Statistical characteristics of annual sum of atmospheric precipitation for 21 meteorological stations of Georgia from 1936 to 2020, mm.

Location	Mean	Max	Min	Range	St Err	St Dev	Cv, %	Conf. Int., 95.0%
Akhaltsikhe	540	853	319	534	11	100	18.5	21.5
Ambrolauri	1038	1443	621	822	20	188	18.1	40.4
Bakuriani	854	1315	556	759	14	130	15.2	28.0
Borjomi	659	949	402	547	12	113	17.1	24.3
Chokhatauri	1793	2628	1059	1569	35	319	17.8	68.9
Dedoplistskaro	591	1001	332	669	14	131	22.2	28.3
Gori	517	758	303	456	10	96	18.5	20.7

Khashuri	621	920	380	540	13	120	19.4	25.9
Khulo	1346	1945	678	1267	31	290	21.5	62.5
Kobuleti	2376	3456	1648	1808	40	367	15.4	79.1
Lagodekhi	1076	1842	660	1182	27	246	22.8	53.0
Mta-sabueti	1165	1670	705	965	24	226	19.4	48.7
Pasanauri	992	1496	437	1059	20	183	18.5	39.5
Sachkhere	950	1385	656	730	18	161	17.0	34.8
Sagarejo	781	1332	433	899	18	163	20.9	35.3
Shovi	1173	1816	700	1116	21	198	16.9	42.7
Tbilisi	513	818	240	578	12	113	22.1	24.4
Telavi	777	1260	529	732	15	137	17.7	29.6
Tianeti	773	1180	299	881	19	179	23.1	38.6
Zestafoni	1296	1806	787	1019	24	224	17.3	48.4
Zugdidi	1798	2440	1158	1282	30	275	15.3	59.3
Average, 21 station	**1030**	**1313**	**773**	**540**	**13**	**120**	**11.6**	**25.9**

As follows from Table 2, the minimum value of the annual sum precipitation was recorded in Tbilisi (240 mm), the maximum - in Kobuleti (3456 mm). The average values of the annual sum of atmospheric precipitation for the entire observation period vary from 513 mm (Tbilisi) to 2376 mm (Kobuleti), the coefficient of variation changes from 15.2% (Bakuriani) to 23.1% (Tianeti).

The average annual precipitation for all observation stations is 1030 mm, the range of change is from 773 mm to 1313 mm, the coefficient of variation is 11.6%.

Fig. 3 presents data on the values of the linear correlation coefficient for the annual sum of atmospheric precipitation between each of the meteorological stations with average values of the annual sum of precipitation for all meteorological stations.

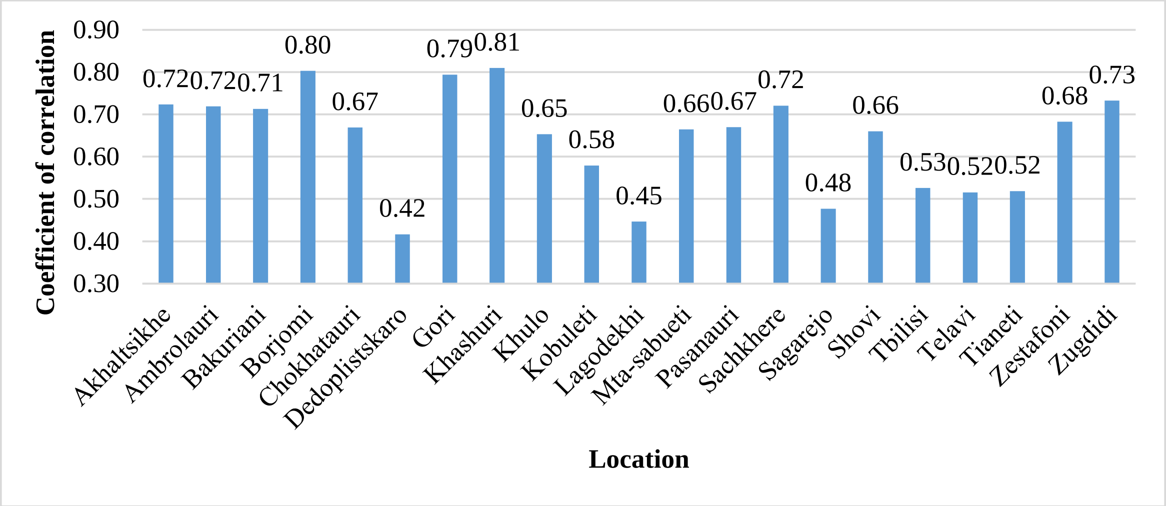

Fig 3. The correlation between the annual amounts of precipitation at each of the meteorological stations with averaged data for all 21 stations on 1936-2020, $\alpha<0.005$.

As follows from Fig. 3, the R value changes from 0.42 (Dedoplistskaro, low correlation) to 0.81 (Khashuri, high correlation). In general, a high correlation ($0.7 \le R < 0.9$) is observed between the indicated parameters in 38.1% of cases, a moderate correlation ($0.5 \le R < 0.7$) in 47.6% of cases, and a low correlation ($0.3 \le R< 0.5$) in 14.3% of cases. Thus, in general, the values of the annual sum of atmospheric precipitation averaged over all meteorological stations are sufficiently representative to compare them with the variations in the annual number of landslides on the territory of Georgia. Note that the representativeness of individual stations in terms of the annual sum of atmospheric precipitation varies from 19 km (Kobuleti, Mta-Sabueti) to 46 km (Gori) around them and averages is 31 km in accordance with [17].

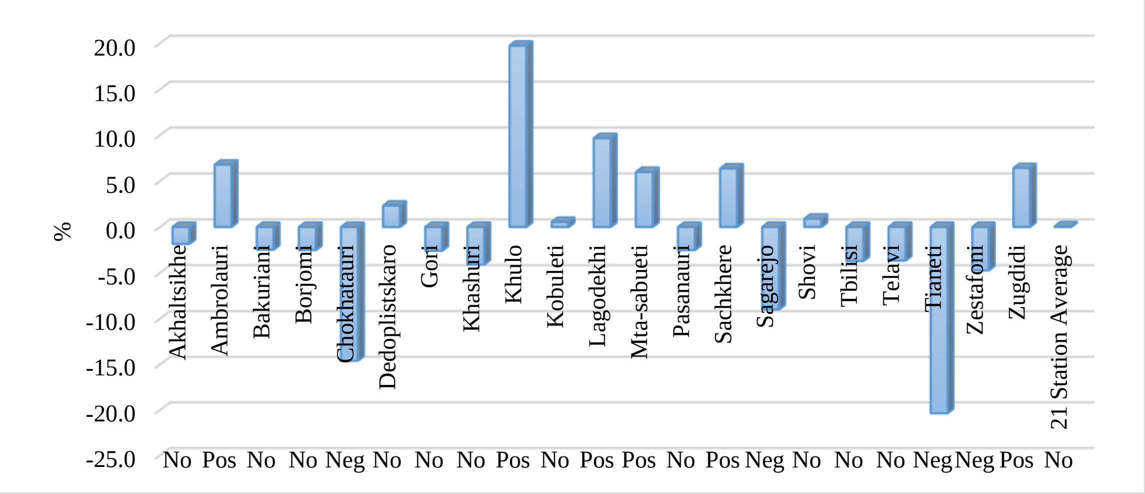

Fig 4. Variability of mean annual sum precipitation for 21 weather stations in 1981-2020 compared with 1936-1975 in relation to the average value of the sum precipitation in 1936-2020 at these stations, %, α≤0.2.

Fig. 4 presents data on the change in the average annual precipitation in 1981-2020 compared to 1936-1975. The difference is normalized to the average annual precipitation in 1936-2020, %.

As follows from Fig. 4 as a result of climate change the variability of the average sum of precipitation in the second period of time compared to the first one for different measurement points is different. So, for 6 measurement points there is an increase in precipitation, for 4 points - a decrease, for 11 points - an insignificant change. For those averaged over all stations, the variability of the annual sum precipitation in the second period of time compared to the first is insignificant. Note that the periodicity of variability of the average annual precipitation per one meteorological station is 11 years (calculated using the Mesosaur program).

Let us consider the nature of the relationship between the annual number of re-activated and new landslides and the annual sum of precipitations. Fig. 5 shows the cross-correlation between values of P_a and the LS cases.

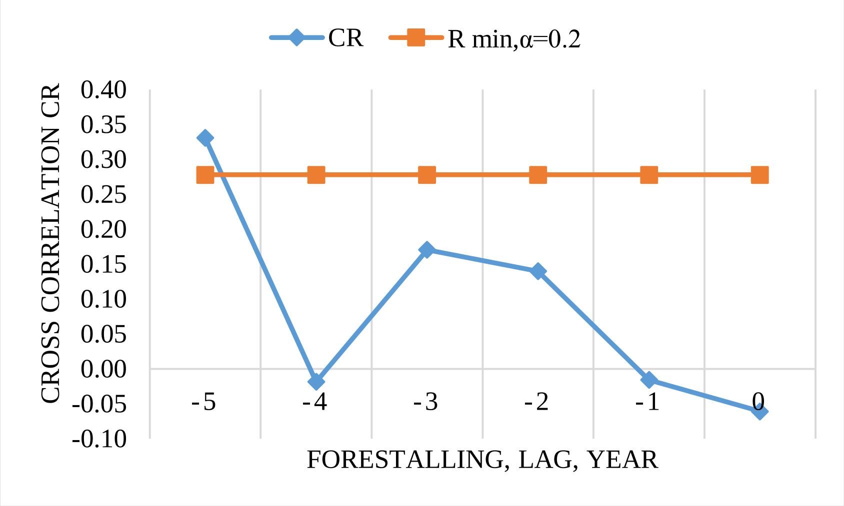

Fig 5. Cross-correlation between the P_a and LS values.

As follows from this figure, a significant correlation between the studied parameters is observed in the fifth lag before the landslide phenomena.

Another Fig. 6 shows the cross-correlation between the moving average of the P_a values and the moving average of the LS cases.

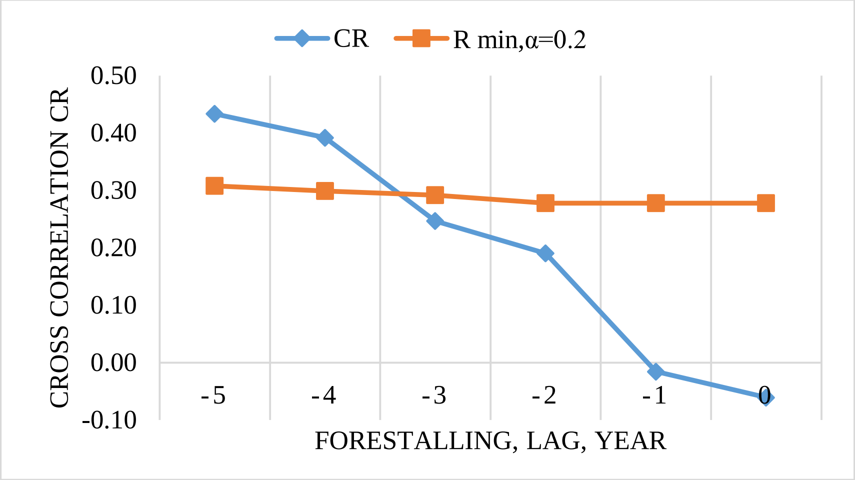

Fig 6. Cross-correlation between the five-year moving average of the P_a and five-year moving average of the LS values.

As follows from Fig. 6, a significant relationship between the studied parameters is observed in the fourth and fifth lags before the landslides. Comparison fig. 5 and 6 shows that in the second case the relationship between P_a values and LS number is more representative than in the first case. Taking into account that in the fifth lag before the onset of landslides, the correlation coefficient is higher than in the fourth lag, a linear regression was built between the five-year moving averages of P_a values and the five-year moving averages of LS number (Fig. 7).

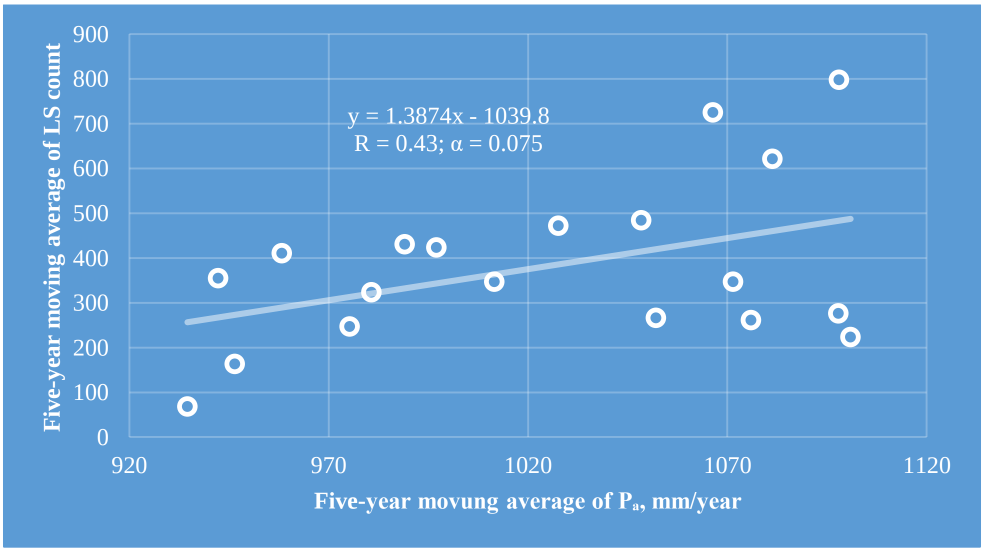

Fig 7. Linear correlation and regression between the five-year moving average of the P_a (1991-1995, 1992-1996, …, 2009-2013) and the five-year moving average of the LS (1996-2000, 2001-2005 ,…, 2014-2018) values.

As follows from Fig. 7, there is a significant direct linear relationship between the values of these parameters, which can be used to predict five-year moving averages of LS cases from the forecast values of the average annual sum precipitation per one meteorological station.

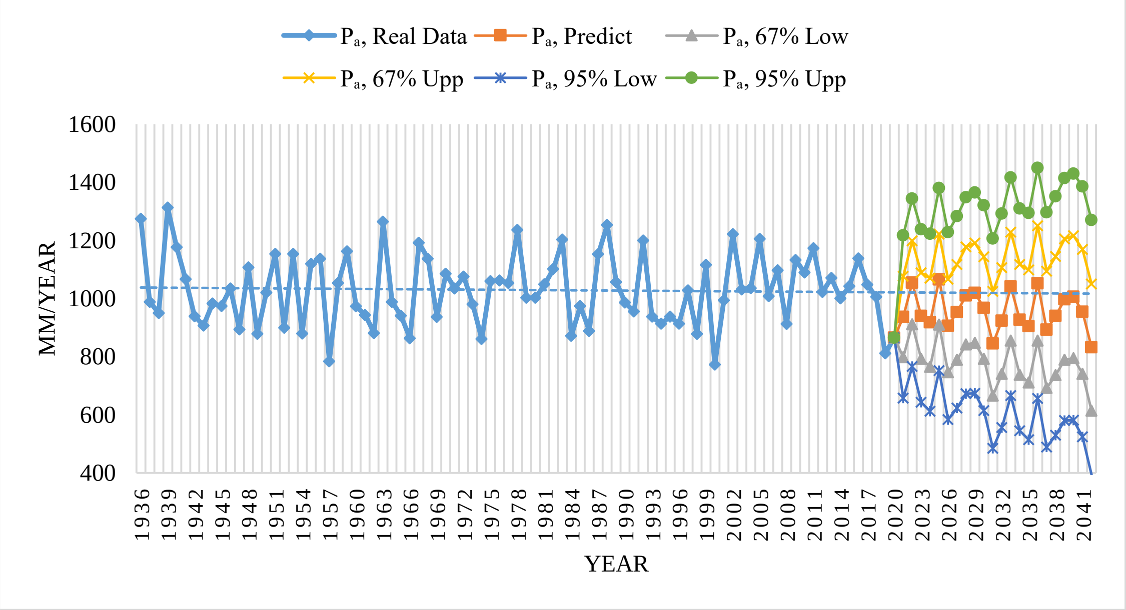

Fig 8. Changeability of average annual amount of precipitation for 21 meteorological stations (P_a) from 1936 to 2020 and its prediction to 2040.

Fig. 8 shows the forecast values of the average annual sum of precipitation per one meteorological station up to 2040, taking into account the eleven-year periodicity in the time-series of observation. Fig. 9 shows data on the expected five-year moving average of re-activated and new landslides cases up to 2041-2045, calculated according to the formula presented in Fig. 7 with using the data of Fig. 8.

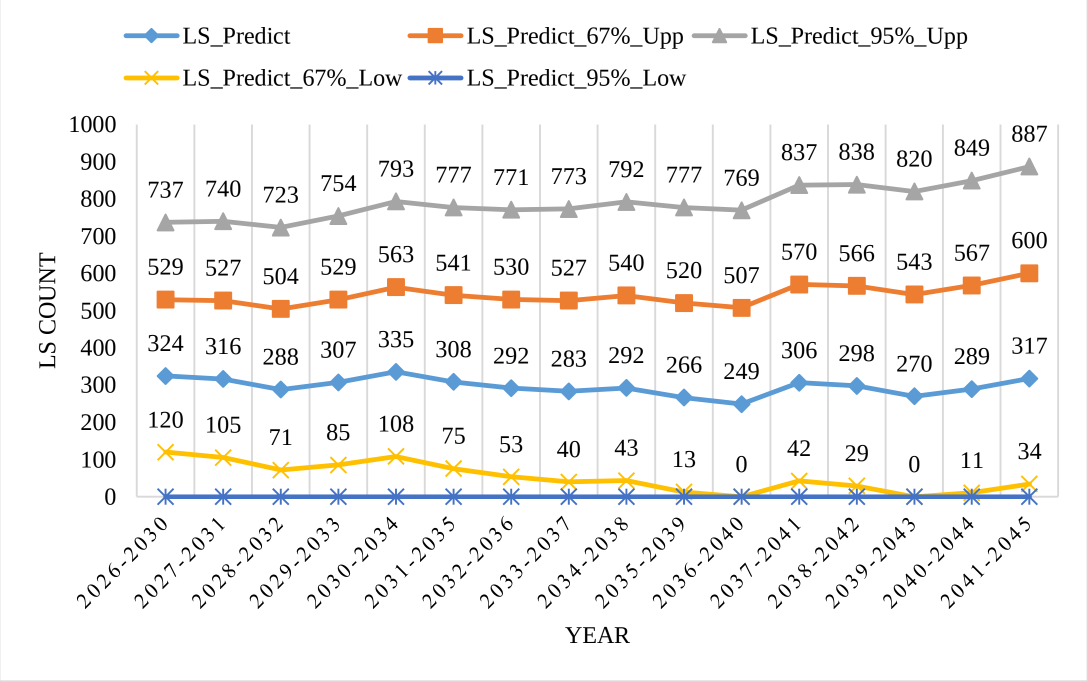

Fig 9. Interval prediction of five-year moving averages of re-activated and new landslides cases from 2026 up to 2045.

Graphs in Fig. 9 represent the center points of the forecast of the number of landslides (LS_Predict), as well as the lower and upper confidence levels of this forecast (LS_Predict_67%_Low, LS_Predict_67%_Upp, etc.). Note that all values of LS_Predict_95%_Low = 0.

Table 3 shows the comparative statistical characteristics of predicted (2026-2045) and real (1996-2018) five-year moving averages of re-activated and new landslides cases.

Table 3. Statistical characteristics of predicted (2026-2045) and real (1996-2018) five-year moving averages re-activated and new landslides cases in Georgia.

Period	2026-2045				1996-2018
Parameter	LS_Predict_ 67%_Low	LS_Predict	LS_Predict_ 67%_Upp	LS_Predict_ 95%_Upp	LS_Real
Mean	52	296	542	790	381
Max	120	335	600	887	798
Min	0	249	504	723	68
Range	120	87	96	164	730
St Err	9.7	5.7	6.4	11.3	42.1
St Dev	39	23	26	45	184
Cv, %	74.4	7.7	4.7	5.7	48.2
Conf. Lev., 95.0%	21	12	14	24	89

As follows from this Table, the average LS_Real values fall within the range of values between LS_Predict and LS_Predict_67%_Upp (296<381<542). The maximum values of LS_Real fall within the range of values between LS_Predict_67%_Upp and LS_Predict_95%_Upp (600<798<887). The minimum values of LS_Real fall within the range of values between LS_Predict and LS_Predict_67%_ Low (0<68<249). Thus, in general, in the next two decades, one should not expect a significant intensification of landslide processes in Georgia due to the expected variability of the annual sum of atmospheric precipitation. However, in certain regions of Georgia, where a significant increase in precipitation is observed (for example, in the vicinity of Khulo, Fig. 4), a significant activation of landslide phenomena is quite possible.

Conclusion

In the near future, we plan to continue similar studies both for the territory of Georgia as a whole and for its individual landslide-prone regions.

Note

This work was presented as a report at the International Eurasia Climate Change Congress "EURACLI – 2022", 29 September 2022 - 01 October 2022, Van,Turkey. http://webportal.yyu.edu.tr/euracli

Acknowledgement

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საქართველოში ატმოსფერული ნალექების საშუალო წლიური ჯამებისა და რე-აქტივიზებული და ახალი მეწყერების შემთხვევებს შორის კავშირის კვლევის ზოგიერთი შედეგი კლიმატის ცვლილების გათვალისწინებით

ამირანაშვილი ა., ჭელიძე თ., სვანაძე დ., წამალაშვილი თ., თვაური გ.

რეზიუმე

მოყვანილია საქართველოში 21 მეტეოროლოგიურ სადგურზე წლიური ჯამური ატმოსფერული ნალექების საშუალოსა (P) და რეაქტივირებული და ახალი მეწყერების შემთხვევების რაოდენობას (LS) შორის კავშირის გამოკვლევის შედეგები და აგრეთვე მოყვანილია LS მნიშვნელობის შეფასება 2045 წლამდე P-ს პროგნოსტული მონაცემების მიხედვით. ნაშრომში გამოყენებულია საქართველოს გარემოს სააგენტოს მონაცემები წლიური ჯამური ატმოსფერული ნალექებისა იმ 21 მეტეოროლოგიურ სადგურზე, რომლებიც განლაგებულია მეწყრულ ზონებში 1936 -დან 2020 წლამდე პერიოდისათვის და აგრეთვე მონაცემები LS -ს შესახებ 1996 -დან 2018 წწ. პერიოდში. მონაცემების ანალიზი ტარდებოდა სტანდარტული მათემატიკური სტატისტიკის მეთოდების გამოყენებით. წლიური ჯამური ატმოსფერული ნალექების სამომავლო ცვლილებების პროგნოზი პერიოდულობის გათვალისწინებით ხორციელდებოდა AAA version of the Exponential Smoothing (ETS) algorithm -ის გამოყენებით.

კერძოდ მიღებულია შემდეგი :

1981-2020 წლებში 1936-1975 წლებთან შედარებით 11 სადგურზე P-ს საშუალო სიდიდეების მნიშვნელოვანი ცვლილება არ შეინიშნება, 6 სადგურზე დაიკვირვება ჯამური ნალექების მატება და 4- ზე შემცირება. აღნიშნულ პერიოდში ყველა სადგურის P –ს საშუალო მნიშვნელობები ცვლილებას არ განიცდიან.

ჩატარებულია ყველა სადგურის საშუალო მნიშვნელობების პროგნოსტული შეფასება 2045 წლამდე ნალექების ცვლილებების პერიოდულობის გათვალისწინებით, რომელიც შეადგენს 11 წელს.

ყველა სადგურის P საშუალოს მნიშვნელობების და LS-ის კროს-კორელაციურმა ანალიზმა აჩვენა, რომ ყველაზე კარგი კორელაციური კავშირი აღნიშნულ პარამეტრებს შორის არსებობს ნალექების მონაცემების ხუთწლიანი წინსწრების დროს. ამის გათვალისწინებით მიღებულია წრფივი რეგრესიის განტოლება ხუთწლიანი მცოცავი ატმოსფერული ჯამური ნალექების საშუალოსა და რე-აქტივირებული და ახალი მეწყერების შემთხვევების ხუთწლიანი მცოცავი საშუალო მნიშვნელობას შორის.

ამ განტოლებისა და P -ს პროგნოსტული მნიშვნელობების გამოყენებით ჩატარებულია LS -ის ხუთწლიანი მცოცავი საშუალო მნიშვნელობების შეფასება 2045 წლამდე.

საკვანძო სიტყვები: ნალექი, მეწყერი, კლიმატის ცვლილება.

Некоторые результаты исследования связи между среднегодовой суммой атмосферных осадков и количеством ре-активированных и новых случаев оползней в Грузии с учетом изменения климата

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Резюме

Приводятся результаты исследования связи между средней для 21 метеорологических станций годовой суммой атмосферных осадков (P) и количеством ре-активированных и новых случаев оползней (LS) в Грузии, а также проведена оценка значений LS до 2045 года по прогностическим данным о P. В работе использованы данные агентства по окружающей среде Грузии о годовой сумме атмосферных для 21 метеорологических станций, расположенных в зонах с оползнями, в период с 1936 по 2020 гг., а также данные о LS в период с 1996 по 2018 гг. Анализ данных проводился с использованием стандартных методов математической статистики. Прогноз будущих изменения годовой суммы осадков с учетом периодичности осуществлялся с использованием AAA version of the Exponential Smoothing (ETS) algorithm.

В частности, получены следующие результаты.

В 1981-2020 по сравнению с 1936-1975 на 11 станциях не наблюдается значимой изменчивости средних значений P, на 6 станциях наблюдается рост суммы осадков и на 4 – уменьшение. Средние по всем станциям значения P в указанные периоды времени изменений не претерпевают.

Проведена оценка прогностических значений среднего по всем станциям значения P до 2045 года с учетом периодичности изменчивости осадков, составляющей 11 лет.

Кросс-корреляционный анализ временных рядов среднего по всем станциям величин P и значений LS показал, что наилучшая корреляционная связь между указанными параметрами наблюдается при пятилетнем упреждении данных об осадках. С учетом этого получено уравнение линейной регрессии между пятилетней скользящей средней суммой атмосферных осадков и пятилетней скользящей средней значений ре-активированных и новых случаев оползней.

С использованием этого уравнения и данных о прогностических значениях P проведена оценка пятилетних скользящих средних значений LS до 2045 года.

Ключевые слова: атмосферные осадки, оползни, изменение климата.