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Study of the Relationship Between the Mean Annual Sum of Atmospheric Precipitation and Re-Activated and New Mudflow Cases in Georgia

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ABSTRACT

Taking into account the earlier statistical analysis of long-term variations in the of annual sum of precipitation for 21 Georgian meteorological stations (P) located in mudflow areas, the relationship between the average annual precipitation for these stations (P_a) and the number of re-activated and new cases of mudflows (MF) was studied. Using previously obtained forecast data for P_a, the MF values were calculated up to 2045. The data of the Georgian Environment Agency on MF for the period 1996-2018 were used.
In particular, the following results are obtained.
Cross-correlation analysis of the time series of P_a and MF 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 between the five-year moving average P_a and the five-year moving average MF is derived.
Using this equation and P_a forecast data, five-year moving averages of re-activated and new mudflow events up to 2045 were estimated.

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

Introduction

Mudflows (MF), like landslides (LS), are one of the types of natural disasters. Mudflow processes are widespread almost everywhere and are dangerous with destruction, often accompanied by human casualties [1-5]. This problem is also very relevant for Georgia, where the number of reactivated and new cases of mudflows only in 1996-2020 exceeded 3200 [6,7]. In this regard, special attention has always been paid to the study of mudflow processes in this area [5–9].

The urgency of this problem increased significantly after the tragedy that happened on August 3, 2023 in the western Georgia in the Shovi resort (Oni municipality of Racha-Lechkhumi and Kvemo Svaneti region), when, as a result of an intense landslide-mudflow process, the central part of the resort was filled with mud flows (Fig. 1,2), which led to the death of more than thirty people [https://civil.ge/archives/554327].

According to preliminary report by the National Environmental Agency the landslide-mudflow was caused by intense melting of glaciers, collapse of rock formations in their headwaters, heavy rains, erosive processes and a glacier runoff.

The Agency said a collapse of a rocky mass on the western side of the Buba glacier had led to its collision with the glacier after coming into motion and caused a collapse of a part of the glacier. The body said the development may have caused an overflow of subglacial waters, with the resulting flow directed through the valley bed at a high speed in the locality [https://agenda.ge/en/news/2023/2999].

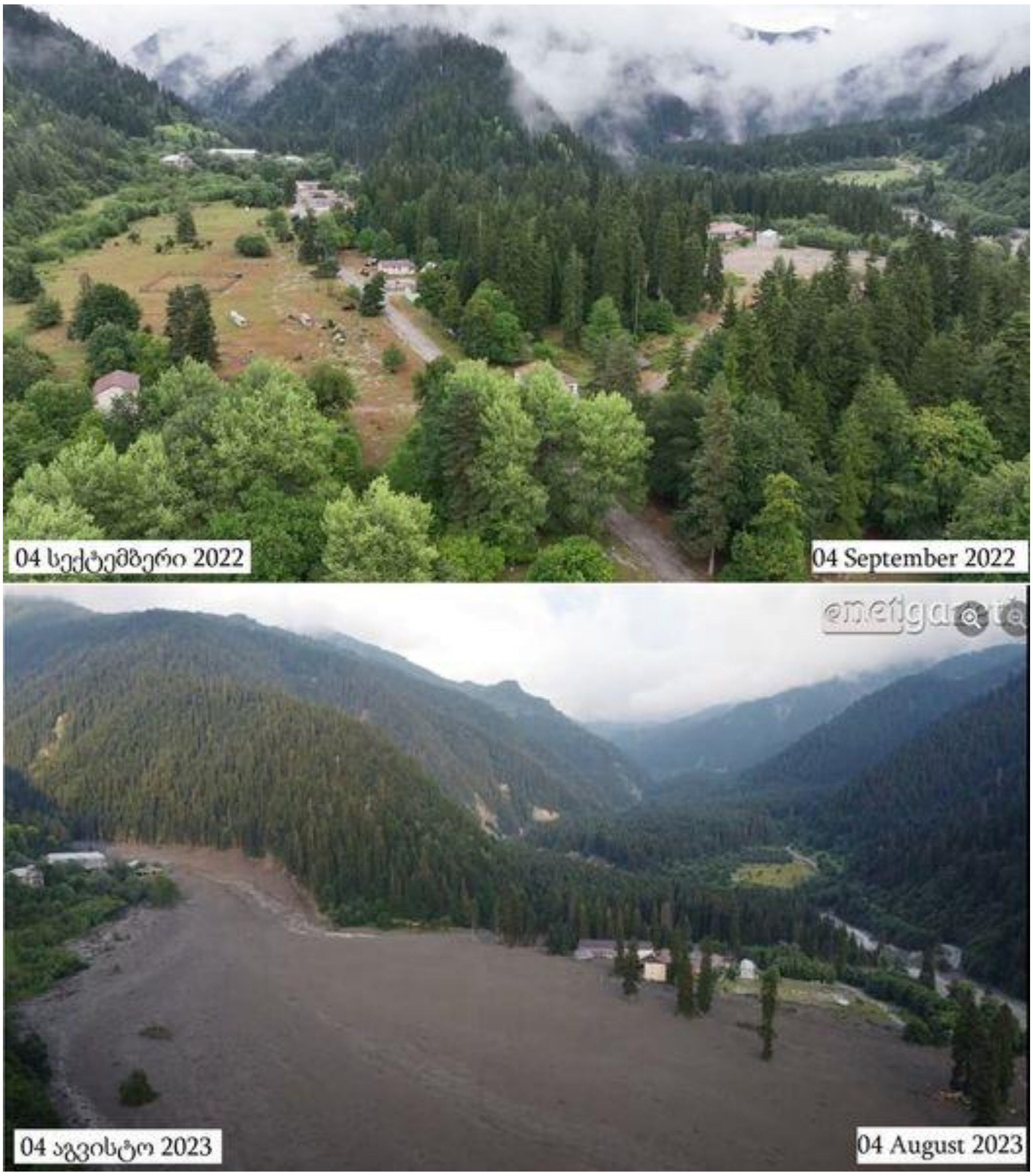

Fig. 1. View of the Shovi resort 11 months before mudflow and on the second day after the mudflow [https://www.facebook.com/photo/?fbid=6326794327369246&set=a.412771738771564]

Mudflows, as well as landslides, depend on many individual and complex processes, in particular, on precipitation. At the same time, the time scale of the influence of atmospheric precipitation on the provocation of mudflows has a wide range - from several tens of minutes to several days, months and years (climatic time scale) [9-12]. For exampe, according to [9] activation of landslide processes in accordance with atmospheric precipitation regime clearly indicates the correlation regularities: the intervals between atmospheric precipitations able to provoke landslide processes, fluctuate within 2,5-5 years, while the sequence line between the increase and deficit of precipitations, which represents one cycle of development of the landslide processes, ranges within 3-8 years.

In recent years, we have carried out a number of additional studies of the relationship between atmospheric precipitation and landslide processes. In this case, data from ground-based and satellite measurements of precipitation were used [13,14]. Thus, using the example of the study of landslides, it was found in [15] that in Georgia, with an increase in the annual amount of atmospheric precipitation, there is a tendency to increase their landslides in accordance with the second degree of the polynomial. In another work [16], 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.

The paper [17] is aimed to assess the rainfall conditions, which can lead to initiation of mass-movement using limited terrestrial and satellite-based data on the summary rainfall and landslide occurrence. In particular, for administrative regions of Georgia precipitation effects on landslides activity for 1, 3, 5, 7, 10, 20 and 30 days before their onset is studied.

This approach can be useful for a lot of regions in the world, where LS and meteorological data are not detailed enough to calculate the standard rainfall intensity/duration threshold graph for landslide occurrence.

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 [18]. Data from the Environmental Agency of Georgia on the P in period 1936 - 2020 and data on LS in period 1996 – 2018 are used.

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.

This work is a continuation of previous studies [18]. 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 mudflows (MF) in Georgia, and an assessment of the MF 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 mudflows 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 mudflow 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 [19].

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; MF - re-activated and new lmudflows cases. The forecast of P_a using the AAA version of the Exponential Smoothing (ETS) algorithm was carried out [20]. Programs Excel 16 and Mesosaur for calculation were used.

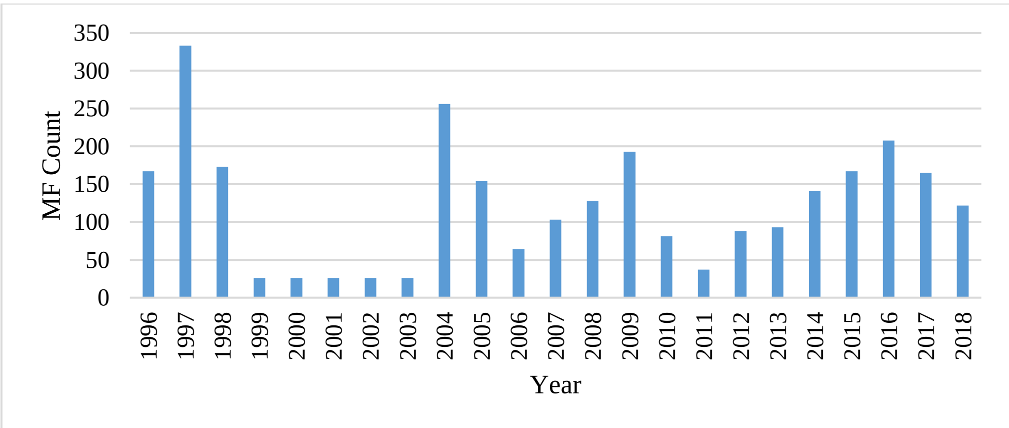

Fig 2. Changeability of re-activated and new mudflows cases in Georgia from 1996 to 2018.

Results and Discussions

Results of statistical analysis of relationship between the P_a and number of re-activated and new cases of mudflows, and the estimated values of MF up to 2045 using predictive data on P_a [18] are presented below in Table 1,2 and Fig. 3-7.

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

Parameter	Mean	Max	Min	Range	St Err	St Dev	Cv, %	Conf. Lev. , 95.0%
MF	122	333	26	307	17	81	66.7	35

Table 1 presents the statistical characteristics of MF cases in Georgia in 1996-2018. On average, 122 cases of MF were recorded per year with a range of changes from 26 to 333 cases. Significant variations in the amount of MF were observed in the specified time period (Cv = 66.7%, Conf. Lev. = 35).

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. 3 shows the cross-correlation between values of P_a and the MF cases.

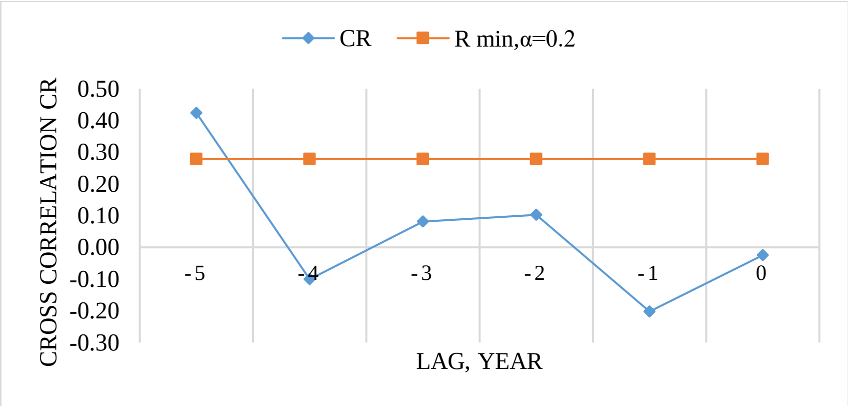

Fig 3. Cross-correlation between the P_a and MF values.

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

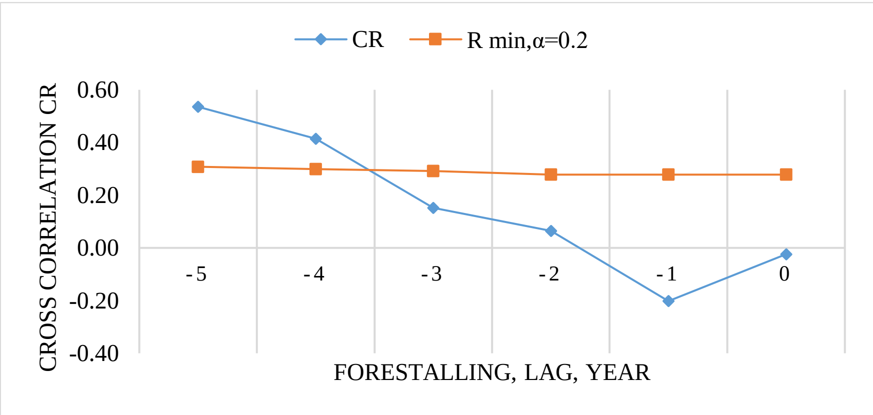

Fig 4. Cross-correlation between the five-year moving average of the P_a and five-year moving average of the MF values.

Another Fig. 4 shows the cross-correlation between the moving average of the P_a values and the moving average of the LS cases. As follows from Fig. 4, a significant relationship between the studied parameters is observed in the fourth and fifth lags before the landslides. Comparison fig. 3 and 4 shows that in the second case the relationship between P_a values and MF number is more representative than in the first case. Taking into account that in the fifth lag before the onset of mudflows, 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 MF number (Fig. 5).

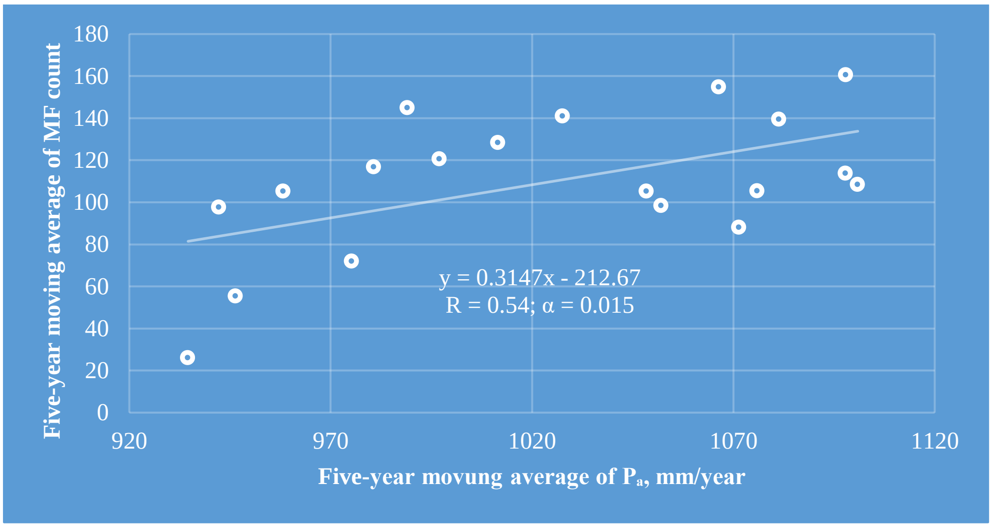

Fig 5. Linear correlation and regression between the five-year moving average of the P_a (1991-1995, 1992-1996, …, 2009-2013) and the five-year moving average of the MF (1996-2000, 2001-2005 ,…, 2014-2018) values.

As follows from Fig. 5, there is a significant direct linear relationship between the values of these parameters, which can be used to predict five-year moving averages of MF cases from the forecast values of the average annual sum precipitation per one meteorological station.

Fig. 6 shows data on the expected five-year moving average of re-activated and new mudflows cases up to 2041-2045, calculated according to the formula presented in Fig. 5 with using the data of predicted five-year moving average of P_a values [18].

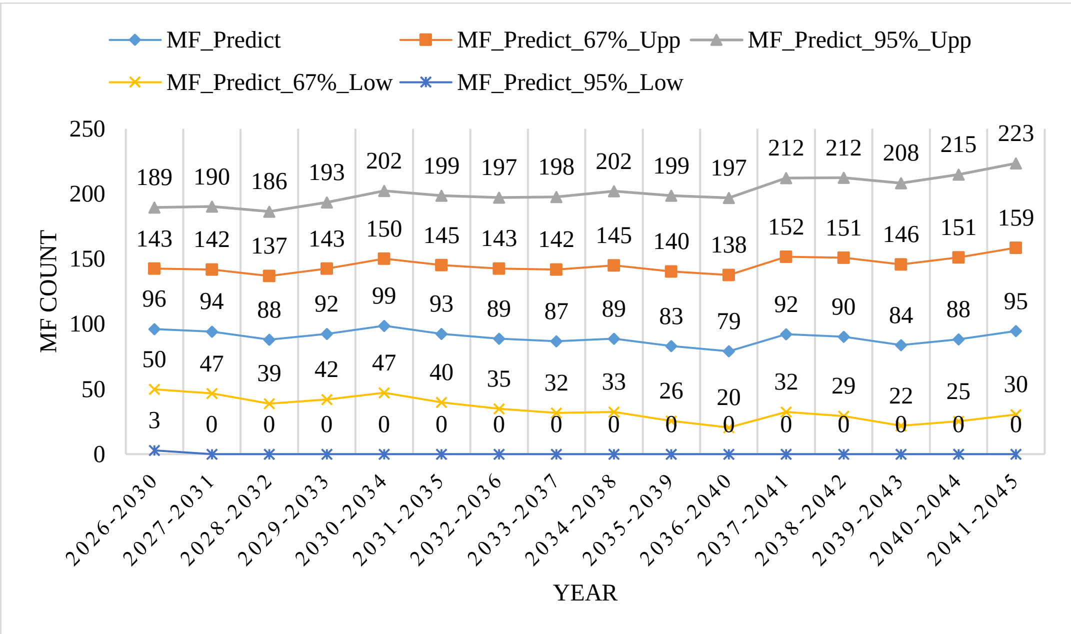

Fig 6. Interval prediction of five-year moving averages of re-activated and new mudflows cases from 2026 up to 2045.

Graphs in Fig. 6 represent the center points of the forecast of the number of mudflows (MF_Predict), as well as the lower and upper confidence levels of this forecast (MF_Predict_67%_Low, MF_Predict_67%_Upp, etc.). Note that all values of MF_Predict_95%_Low = 0.

Table 2 shows the comparative statistical characteristics of predicted (2026-2045) and real (1996-2018) five-year moving averages of re-activated and new mudflows cases.

Table 2. Statistical characteristics of predicted (2026-2045) and real (1996-2018) five-year moving averages re-activated and new mudflows cases in Georgia.

Period	2026-2045				1996-2018
Parameter	MF_Predict_ 67%_Low	MF_Predict	MF_Predict_ 67%_Upp	MF_Predict_ 95%_Upp	MF_Real
Mean	34	90	145	201	110
Max	50	99	159	223	161
Min	20	79	137	186	26
Range	29	20	22	37	135
St Err	2.3	1.3	1.5	2.6	7.9
St Dev	9.0	5.1	5.8	10.3	33.7
Cv, %	26.4	5.7	4.0	5.1	30.8
Conf. Lev., 95.0%	4.6	2.6	2.9	5.2	15.6

As follows from this Table, the average MF_Real values fall within the range of values between MF_Predict and MF_Predict_67%_Upp (90<110<145). The maximum values of MF_Real fall within the range of values between MF_Predict_67%_Upp and MF_Predict_95%_Upp (159<161<223). The minimum values of MF_Real fall within the range of values between MF_Predict and MF _Predict_67%_ Low (20<26<79). Thus, in general, in the next two decades, one should not expect a significant intensification of mudflow 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 a significant activation of mudflow phenomena (as well as landslides [18]) quite possible.

Finally, in Fig. 7 and 8 linear correlation and regression between LS and MF cases and between five-year moving averages LS and MF cases in Georgia in 1996-2018 are presented.

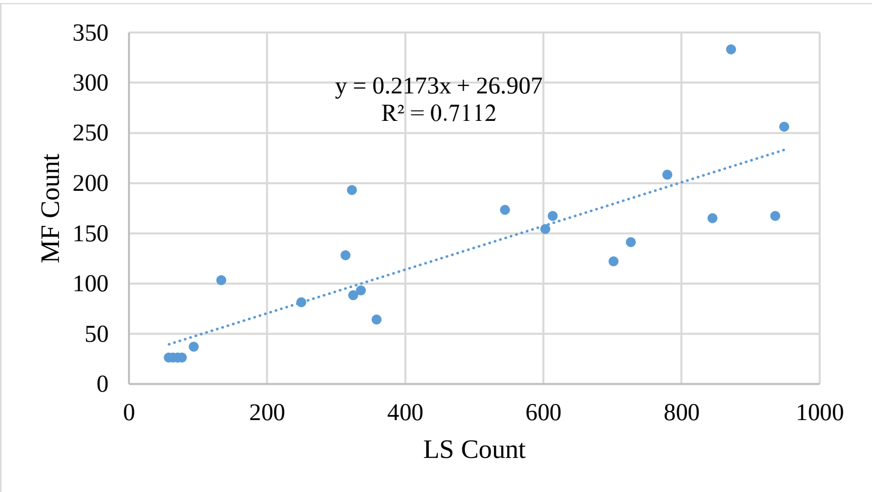

Fig.7. Linear correlation and regression between LS and MF cases in Georgia in 1996-2018.

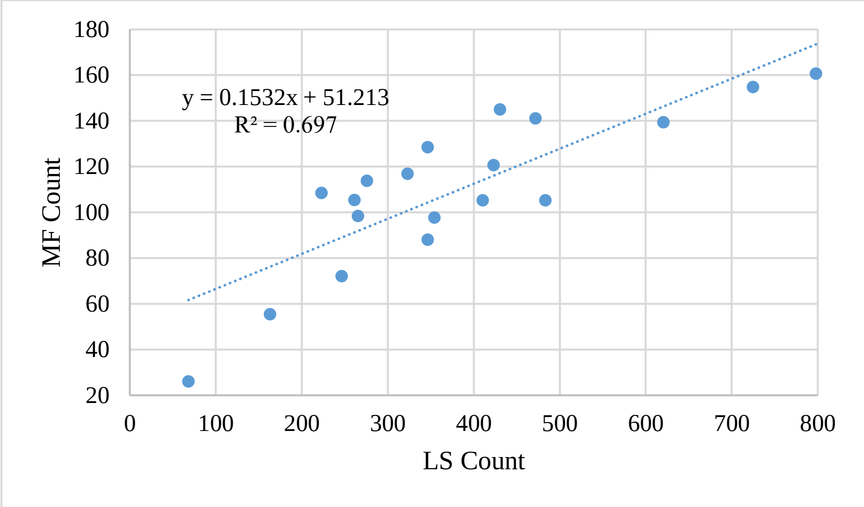

Fig.8. Linear correlation and regression between five-year moving averages LS and MF cases in Georgia in 1996-2018.

The linear correlation coefficient between LS and MF is 0.84 and 0.83, respectively (Fig. 7 and 8, high correlation [19]).

Conclusion

In the future, using the data of the new catalog of natural hazards being prepared in Georgia [21,22], we plan to continue more detailed studies of landslides and mudflows both for the territory of Georgia as a whole and for its individual regions, taking into account climate change [4].

It is also planned to carry out work on the implementation of the existing early warning system for the activation of landslide / mudflow events [23]. In addition, it is planned to develop research on long-term and short-term forecasting of landslide and mudflow processes using ground-based, radar and satellite information on the parameters associated with these processes [13,14,17,24-27].

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საქართველოში ატმოსფერული ნალექების ჯამური საშუალო წლიური და რე-აქტივიზებული და ახალი ღვარცოფების შემთხვევებს შორის კავშირის კვლევა

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

რეზიუმე

წლიური ნალექების რაოდენობის გრძელვადიანი ცვალებადობის ადრინდელი სტატისტიკური ანალიზის გათვალისწინებით ღვარცოფულ რაიონებში მდებარე 21

საქართველოს მეტეოროლოგიური სადგურისთვის (P), შესწავლილია კავშირი ამ სადგურების საშუალო წლიურ ნალექს (P_a) და რეაქტივირებულთა და ღვარცოფის (MF) ახალი შემთხვევების რაოდენობას შორის. P_a-ისთვის ადრე მიღებული საპროგნოზო მონაცემების გამოყენებით, გამოითვალა MF მნიშვნელობები 2045 წლამდე. გამოყენებული იქნა საქართველოს გარემოს დაცვის სააგენტოს მონაცემები MF-ის შესახებ 1996-2018 წლებში.
კერძოდ, მიღებულია შემდეგი შედეგები.
P_a და MF მნიშვნელობების დროის სერიების კროს-კორელაციურმა ანალიზმა აჩვენა, რომ საუკეთესო კორელაცია მითითებულ პარამეტრებს შორის შეინიშნება ნალექების მონაცემების მცოცავი ხუთწლიანი ინტერვალისათვის. ამის გათვალისწინებით, მიღებულია წრფივი რეგრესიის განტოლება ხუთწლიან მოძრავ საშუალო P_a-სა და ხუთწლიან მოძრავ საშუალო MF-ს შორის.
ამ განტოლებისა და P_a პროგნოზის მონაცემების გამოყენებით, შეფასდა 2045 წლამდე ხელახლა გააქტიურებული და ახალი ღვარცოფული მოვლენების ხუთწლიანი მოძრავი საშუალო მაჩვენებლები.

საკვანძო სიტყვები: ნალექი, ღვარცოფი, კლიმატის ცვლილება.

Изучение связи между среднегодовой суммой атмосферных осадков и количеством ре-активированных и новых случаев селей в Грузии

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Резюме

С учетом проведенного ранее статистического анализа многолетних вариаций суммы годовых осадков для 21 метеостанции Грузии (P), расположенных в селевых районах, изучена связь между среднегодовым количеством осадков для этих станций (P_a) и количеством ре-активированных и новых случаев селей (MF). С использованием ранее полученных прогнозных данных для P_a проведены расчеты значений MF до 2045 г. Использовались данные Агентства окружающей среды Грузии по MF за период 1996-2018 гг.
В частности, получены следующие результаты.
Кросс-корреляционный анализ временных рядов значений P_a и MF показал, что наилучшая корреляция между указанными параметрами наблюдается при пятилетнем упреждении данных об осадках. С учетом этого получено уравнение линейной регрессии между пятилетним скользящим средним значением P_a и пятилетним скользящим средним значением MF.
Используя это уравнение и прогностические данные о P_a, были оценены пятилетние скользящие средние ре-активированных и новых случаев селей до 2045 года.

Ключевые слова: атмосферные осадки, сели, изменение климата.