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Peculiarities of Intra-Annual Distribution of Landslide Recurrence in Adjara and Guria Regions (Western Georgia) and in Eastern Georgia and their Relationship with Monthly Sums of Precipitation

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ABSTRACT

Correlation and regression relationships between the intra-annual distribution (%) of the relative number of landslides and the relative precipitation amounts in the month of the landslide occurrence were studied for the regions of Adjara and Guria (Georgia), and Eastern Georgia. Specifically, it was found that the intra-annual distribution of landslides across the studied territories of Georgia is quite uneven. The highest relative number of landslides in Adjara and Guria occurs in October (18.7%), and the lowest in August (3.4%). The highest relative number of landslides in Eastern Georgia occurs in June (12.4%), and the lowest in July (6.4%). In Adjara and Guria in the linear approximation, correlation coefficient R between intra-annual distribution of the recurrence of landslides and mean sum of precipitation during the month of their activation is moderate (R=0.62), and in the case of approximation by a third-degree polynomial - index of correlation R' is high (R'=0.80). In Eastern Georgia between specified parameters mostly linear correlation is observed (R=0.60, moderate correlation). The level of nonlinear relationships does not go beyond moderate correlation.

Key words: *natural disasters, landslides, precipitation, correlation and regression analysis.*

Introduction

Landslides are a type of natural disaster that often cause significant environmental damage, lead to significant human casualties, and are widespread in many countries worldwide [1–4], including Georgia [5–13]. Landslide activation, along with many natural and anthropogenic factors, is also caused by prolonged, intense, or extreme precipitation [14-25]. Landslides have a seasonal pattern, which is often associated with seasonal variations in precipitation [26–30].

For example, in study [27] investigates the relationship between landslides and annual precipitation as well as selected monthly landslide distributions and their connection with weather anomalies in southern Lower Saxony, northern Hesse and the surroundings. Data about 394 landslide events between 1901 and 2016 was used. It was received that landslide distributions are correlated with precipitation records of a synthetic precipitation series as a representative for the study area. The annual landslide distribution shows an overall increasing number of events with alternating periods of low and high landslide activity. Correlation with the annual precipitation predominantly reveals a more frequent occurrence of landslides in humid years. The monthly landslide distribution between 1901 and 2016 shows a first accumulation of events in winter months (January–March: 31%) and a second one in summer months (June–August: 32%). In general, this monthly landslide distribution follows the annual course of precipitation. Particular monthly landslide distributions are apparent for periods of increased landslide activity which coincide with exceptional long-term winter and summer precipitation trends. In these periods the monthly distributions widely follow the annual precipitation courses. Overall, the results show that the precipitation is basically suitable for an explanation for the occurrence of landslide events. Whereas the annual precipitation is only partially meaningful for the annual landslide activity, the influence of exceptional seasonal precipitation is reflected in the monthly landslide distributions. The authors believe that the results provide a promising basis for more detailed analyses of the relationship between landslides and the precipitation in the study area [27].

In work [30] the correlation and regression relationship between the intra-annual distribution (%) of the number of landslides (LS) and the precipitation sums in the month when the landslide occurred and the accumulated sums for the month and 1...11 months before the landslide, P(1)…P(12), respectively, were studied. In particular, it was found that the intra annual distribution of landslides across the territory of Georgia is rather uneven. The highest number of landslides occurs in July and September (11.7% and 11.0%, respectively), while the lowest occur in January and November (5.3% and 5.6%, respectively). A moderate correlation is observed between the intra-annual distribution of LS with the intra-annual distributions of P(9)…(12). For the pairs LS – P(1) and LS – P(8), the correlation is low. For the remaining cases, the correlation is negligible. Linear regression equations between the parameters under study are presented.

This work is a continuation of the study [30]. Below are the results of analysis of peculiarities of intra-annual distribution of landslide recurrence in Adjara and Guria regions (Georgia) and in Eastern Georgia and their relationship with monthly sums of precipitation.

Study area, material and methods

Study area: Adjara and Guria regions (Georgia) and Eastern Georgia.

Data on the number of landslides (LS) with a known month of their activation were taken from the catalog [9] (Table 1). Adjara, Guria. Period of observation: 1968,2008-2010,2012-2022, Total LS Number – 145. Eastern Georgia. Period of observation: 1968,1973-1976,1983,1984,1988,1989,2001,2002,2004-2007,2011-2015,2017-2022, Total LS Number – 183. Table 1 also provides data on the number of landslides per year in different months (LS Numb/Year).

The data from the National Environmental Agency on monthly precipitation from 10 meteorological stations in Adjara and Guria, as well as from 27 meteorological stations in Eastern Georgia were used (Table 2). List of meteorological stations, their coordinates and locations in [24] are presented. Table 2 data on mean sum of precipitation during the months of landslides activation in Adjara, Guria and Eastern Georgia are presented.

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [31]. The following designations will be used below: R^2 – coefficient of determination; R – coefficient of linear correlation; R' - index of correlation for nonlinear equations.

The degree of correlation was determined in accordance with [31]: 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 ($0 \le R < 0.3$).

Table 1. Data on landslides numbers in Adjara, Guria and Eastern Georgia by months according to [9].

Region	Adjara, Guria			Eastern Georgia		
Parameter	LS Number	Number of years	LS Numb/Year	LS Number	Number of years	LS Numb/Year
Jan	3	2	1.5	8	5	1.6
Feb	5	3	1.667	8	4	2
Mar	12	4	3	16	8	2
Apr	19	8	2.375	24	12	2
May	12	5	2.4	24	12	2
Jun	24	7	3.429	35	12	2.917
Jul	9	6	1.5	9	6	1.5
Aug	4	4	1	16	9	1.778
Sep	27	9	3	17	9	1.889
Oct	22	4	5.5	13	6	2.167
Nov	3	2	1.5	7	4	1.75
Dec	5	2	2.5	6	3	2
Jan-Dec	145		29.371	183		23.601

Table 2. Data on mean sum of precipitation during the months of landslides activation in Adjara, Guria and Eastern Georgia.

Parameter	Mean sum of precipitation during the months of LS activation, mm	
Region	Adjara, Guria	Eastern Georgia
Jan	186.2	25.3
Feb	128.6	36.6
Mar	157.1	80.8
Apr	67.5	78.3
May	58.6	122.3
Jun	93.7	117.8
Jul	150.5	59.6
Aug	109.8	54.9
Sep	352.3	65.8
Oct	389.1	46.6
Nov	130.7	47.4
Dec	214.4	49.9
Jan-Dec	2038.53	785.24

Results and discussion

Results in Table 3 and Fig. 1-4 are presented.

In Table 3 statistical characteristics of intra-annual distribution of landslides numbers in year and mean sum of precipitation during the months of landslides activation in Adjara, Guria and Eastern Georgia (data from Tables 1 and 2) are presented.

Table 3. Statistical characteristics of intra-annual distribution of landslides numbers in year and mean sum of precipitation during the months of landslides activation in Adjara, Guria and Eastern Georgia

Parameter	LS Numb/Year		Mean sum of precipitation during the months of LS activation, mm	
Region	Adjara, Guria	Eastern Georgia	Adjara, Guria	Eastern Georgia
Max	5.5	2.92	389.1	122.3
Min	1.0	1.5	58.6	25.3
Average	2.45	1.97	169.9	65.4
St Dev	1.22	0.36	104.1	29.9

Fig. 1 and 2 shows the intra-annual distribution of the recurrence of landslides and sum of precipitation during the month of their activation in Adjara, Guria and Eastern Georgia, normalized by their sum values (Table 3).

Values of LS Numb/Year and their normalized values change as follows (Tables 1, 3, Fig. 1,2). Adjara, Guria: from 1.0 (or 3.4 %) in August to 5.5 (or 18.7 %) in October with average value – 2.45; Eastern Georgia: from 1.5 (or 6.4 %) in July to 2.92 (or 12.4 %) in June with average value – 1.97.

Mean sum of precipitation during the months of LS activation and their normalized values change as follows (Tables 2, 3, Fig. 1,2). Adjara, Guria: from 58.6 mm (or 2.9 %) in May to 389.1 mm (or 19.1 %) in October with average value – 169.9 mm; Eastern Georgia: from 25.3 mm (or 3.2 %) in January to 122.3 mm (or 15.6 %) in May with average value – 65.4 mm.

As follows from Fig. 1 and 2 in general, despite the heterogeneity of the initial data (Tables 1 and 2), the intra-annual distribution of landslide recurrences in the studied regions of Georgia is to a certain extent synchronous with the intra-annual distribution of precipitation recurrences.

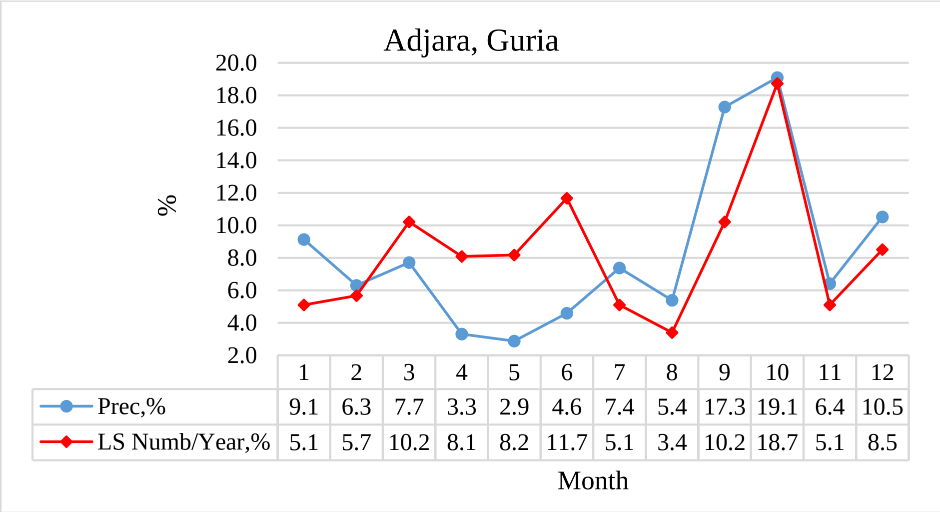

Fig. 1. Intra-annual distribution of the recurrence of landslides and sum of precipitation during the month of their activation in Adjara and Guria, normed on their average values.

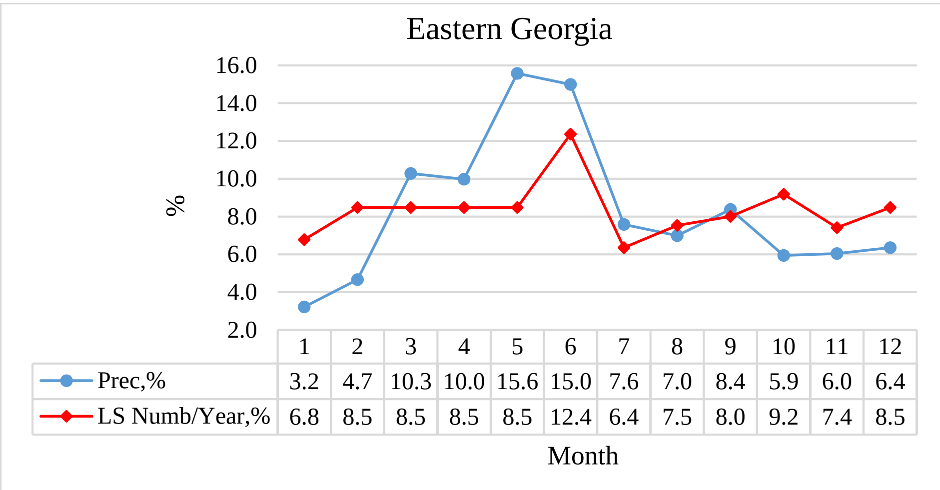

Fig. 2. Intra-annual distribution of the recurrence of landslides and sum of precipitation during the month of their activation in Eastern Georgia, normed on their average values.

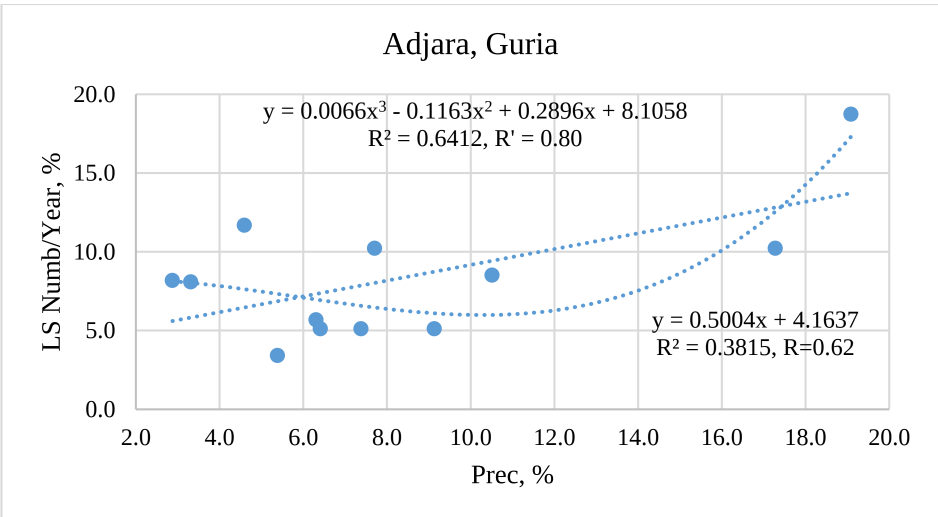

Fig. 3. Connection between intra-annual distribution of the recurrence of landslides and mean sum of precipitation during the month of their activation in Adjara and Guria.

At the same time, in Adjara and Guria (Fig. 3) in the linear approximation, correlation between intra-annual distribution of the recurrence of landslides and mean sum of precipitation during the month of their activation is moderate (R=0.62), and in the case of approximation by a third-degree polynomial - high (R'=0.80).

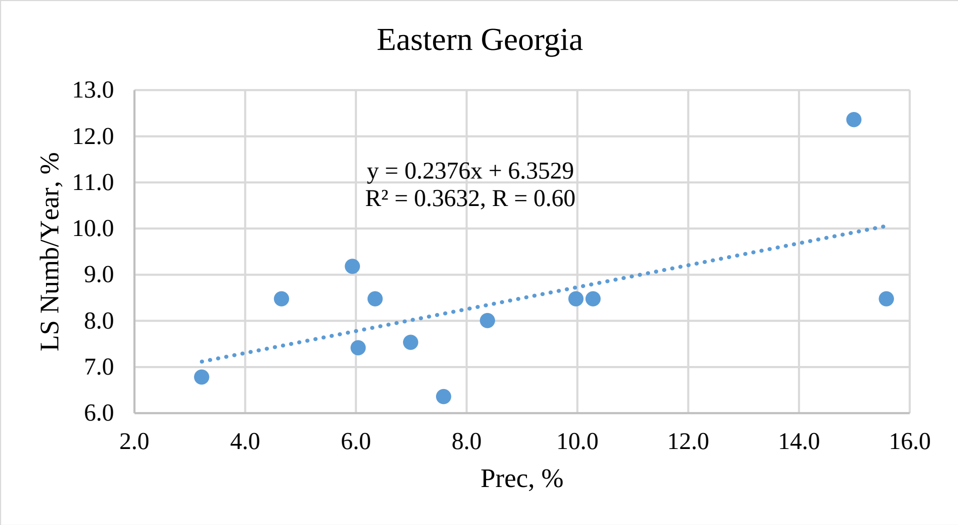

Fig. 4. Connection between intra-annual distribution of the recurrence of landslides and mean sum of precipitation during the month of their activation in Eastern Georgia.

In Eastern Georgia (Fig. 4) between specified parameters mostly linear correlation is observed (R=0.60, moderate correlation). The level of nonlinear relationships does not go beyond moderate correlation.

Our earlier study [30] showed that for Georgia as a whole the value of the linear correlation coefficient between the intra-annual distributions of landslides number and mean sum of precipitation during the month of their activation is 0.42 (low correlation), which is below the same value for Adjara, Guria (R=0.62, moderate correlation, Fig. 3) and for Eastern Georgia (R=0.60, moderate correlation, Fig. 4).

Note, that according to [32] mean monthly sum precipitation in Adjara, Guria and Eastern Georgia in 1961-1990 are respectively equal 155.7 and 61.3 mm. Comparison of these data with the data in Table 3 shows that mean monthly sum precipitation during the months of LS activation more than their average long-term values on 9.1 % in Adjara, Guria and on 6.9 % in Eastern Georgia.

Conclusion

In the future, as new data accumulates, we plan to refine the results obtained in this study. We also plan to conduct research assessing the role of various factors (including precipitation) in landslide activation in different seasons using artificial intelligence methods in both steady-state and dynamic modes.

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მეწყრის განმეორების შიდა წლიური განაწილების თავისებურებები აჭარისა და გურიის რეგიონებში (დასავლეთ საქართველო) და აღმოსავლეთ საქართველოში და მათი კავშირი ყოველთვიურ ნალექების რაოდენობასთან

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

რეზიუმე

აჭარის, გურიისა და აღმოსავლეთ საქართველოს რეგიონებისთვის შესწავლილი იქნა მეწყერების ფარდობითი რაოდენობის შიდაწლიურ განაწილებასა (%) და მეწყრული თვის განმავლობაში მოსული ნალექების ფარდობით რაოდენობას შორის კორელაციური და რეგრესიული კავშირები. კერძოდ, დადგინდა, რომ საქართველოს შესწავლილ ტერიტორიებზე მეწყერების წლიური განაწილება საკმაოდ არათანაბარია. აჭარასა და გურიაში მეწყერების ყველაზე მაღალი ფარდობითი რაოდენობა ოქტომბერში (18.7%), ხოლო ყველაზე დაბალი - აგვისტოში (3.4%) ფიქსირდება. აღმოსავლეთ საქართველოში მეწყერების ყველაზე მაღალი ფარდობითი რაოდენობა ივნისში (12.4%), ხოლო ყველაზე დაბალი - ივლისში (6.4%) ფიქსირდება. აჭარასა და გურიაში, მეწყერის განმეორებადობის წლიური განაწილებისა და მათი გააქტიურების თვის საშუალო ნალექებს შორის კორელაციის კოეფიციენტი R ზომიერია (R=0.62) წრფივი მიახლოებით, ხოლო მესამე ხარისხის პოლინომური მიახლოებით კორელაციის ინდექსი R' მაღალია (R'=0.80). აღმოსავლეთ საქართველოში ამ პარამეტრებს შორის უპირატესად წრფივი კორელაცია შეინიშნება (R=0.60, ზომიერი კორელაცია). არაწრფივი დამოკიდებულებების დონე არ აღემატება ზომიერ კორელაციას.

საკვანძო სიტყვები: სტიქიური უბედურება, მეწყერი, ნალექი, კორელაციური და რეგრესიული ანალიზი.

Особенности внутригодового распределения частоты оползней в регионах Аджария и Гурия (Западная Грузия) и в Восточной Грузии и их связь с месячными суммами осадков

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Резюме

Для регионов Аджарии и Гурии (Грузия) и Восточной Грузии были изучены корреляционные и регрессионные зависимости между внутригодовым распределением (%) относительного числа оползней и относительным количеством осадков в месяце возникновения оползня. В частности, было установлено, что внутригодовое распределение оползней на исследуемых территориях Грузии довольно неравномерно. Наибольшее относительное число оползней в Аджарии и Гурии приходится на октябрь (18.7%), а наименьшее — на август (3.4%). Наибольшее относительное число оползней в Восточной Грузии приходится на июнь (12.4%), а наименьшее — на июль (6.4%). В Аджарии и Гурии при линейной аппроксимации коэффициент корреляции R между внутригодовым распределением повторяемости оползней и средней суммой осадков за месяц их активации является умеренным (R=0,62), а в случае аппроксимации полиномом третьей степени – индекс корреляции R' высок (R'=0,80). В Восточной Грузии между указанными параметрами в основном наблюдается линейная корреляция (R=0.60, умеренная корреляция). Уровень нелинейных зависимостей не выходит за рамки умеренной корреляции.

Ключевые слова: стихийные бедствия, оползни, атмосферные осадки, корреляционный и регрессионный анализ.