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Intra-Annual Distribution of Landslide Recurrence in Georgia and its Relationship with Monthly and Cumulative Multi-Month Sums of Precipitation

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ABSTRACT

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.

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

Introduction

Landslides, as a type of natural disaster, often cause significant damage to the environment in many countries around the world [1–3], including Georgia [4–10]. In particular, [10] presents the results of a statistical analysis of data from the Geological Department of the Environmental Agency of Georgia on the annual number of activated and newly formed landslides (LS) for the period from 1995 to 2024. The number of landslides varies in the range from 56 to 1360 with an average annual value of 581. The trend in LS values has the form of a seventh-degree polynomial. In a subsequent study [11], an interval forecast of LS values up to 2030 was carried out taking into account the periodicity in the observation series. The mean predicted LS value for 2025–2030 was found to be 1582 ± 107, with a 68% confidence interval from 875 ± 107 to 2289 ± 232.

Landslide activation is caused by many natural and anthropogenic factors, including the influence of prolonged, intense, or extreme precipitation [12].

In recent years, a number of studies have been conducted in Georgia to identify the short-term (hours, days, months) [13–16] and long-term (years, climate scale) effects of precipitation on landslide and mudflow activation [17–20]. These studies used landslide and mudflow data presented in [7, 8], as well as ground-based, radar, and satellite precipitation data, taking into account their representativeness depending on the distance to the measurement point. A detailed review of these studies is presented in [21].

In our latest work [22] a detailed statistical analysis of the relationship between monthly and accumulated multi-month precipitation sums and the number of landslides in 12 regions of Georgia is presented. Landslide data with a known month and year of activation were used (a total of 788 landslide events from 1961 to 2022). For the analysis, the precipitation sum for the month of landslide activation (P1) was determined, as well as the accumulated precipitation sum for the month of activation and for 1 month (P2), 2 months (P3), …, and 11 months (P12) prior to landslide occurrence.

Specifically, the following results were obtained. The relationship between average precipitation values (threshold values) and monthly precipitation duration during the month of landslide activation and before landslide activation in Georgia and its individual regions was determined. It was found that, overall, in eastern Georgia (including the Samtskhe-Javakheti region), landslide activation occurs with significantly lower precipitation sums than in western Georgia. The average P1 values are 76 and 156 mm, respectively, and the P12 values are 684 and 1588 mm. The linear correlation between the number of landslides and the P1…P12 values across the regions of Georgia is low for P1 and moderate for P2…P12. The sum of precipitation associated with landslides exceeds the general long-term average monthly precipitation by approximately 16%. For Georgia as a whole, the dependence of the number of landslides on the P1 and P12 values has the form of a fifth-order polynomial (sequentially: slight increase – plateau – strong increase). For P1 values, the precipitation sum plateau, after which a strong increase in the number of landslides begins, covers the range from 62 to 149 mm, and for P12 – from 914 to 1588 mm (the number of landslides is ≈ 108–114).

This work is a continuation of the study [22]. Below are the results of the analysis of the relationship between the intra-annual distribution of landslide frequency in Georgia and monthly and accumulated multi-month precipitation sums.

Study area, material and methods

Study area is Georgia.

Data on the number of landslides with a known month of their activation were taken from the catalog [7]. Period of observation - from 1961 to 2022. Total - 788 landslide cases.

Data National Environmental Agency about monthly sum of atmospheric precipitations for 78 meteorological stations are used. List of meteorological stations, their coordinates and locations in [22] are presented.

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [23].

The following designations will be used below: R – coefficient of linear correlation; 1....12 - January .... December; LS(1)...LS(12) - the ratio of the number of landslides from January to December to their annual number, %; P(1)...P(12) - the ratio of the sum of precipitation in the month with landslide activation to their cumulative sum in the month and 1…11 months before the landslide, respectively, %;

The degree of correlation was determined in accordance with [23]: 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 Fig. 1-3 are presented.

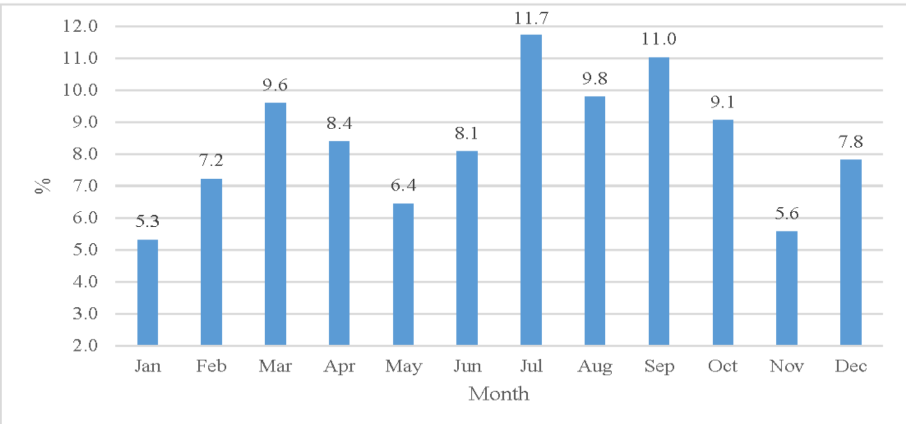

Fig. 1. Intra-annual distribution of landslide recurrence in Georgia.

In Fig. 1 intra-annual distribution of landslide recurrence in Georgia is presented. As this figure shows, the intra annual distribution of landslides across Georgia is quite 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).

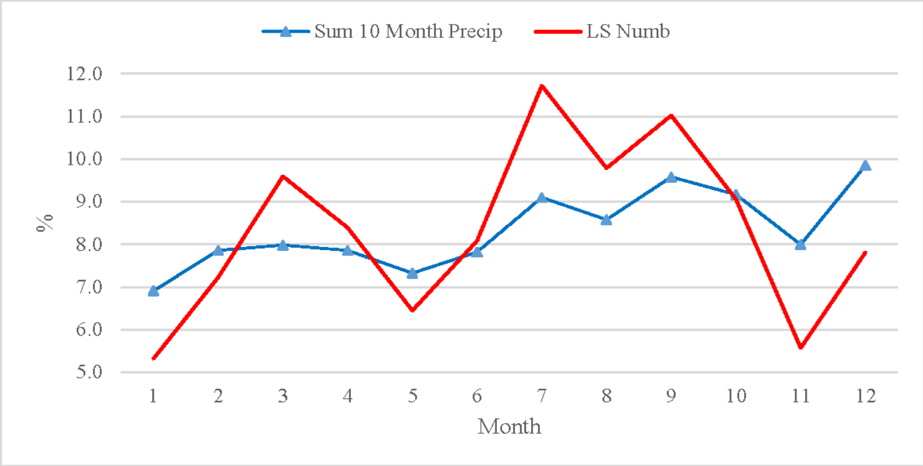

Fig. 2. Intra-annual distribution of the recurrence of landslides and P(10) in Georgia.

In Fig. 2 as an example intra-annual distribution of the recurrence of landslides and P(10) in Georgia is presented. The correlation coefficient between the specified distributions is 0.66 (Fig. 3, moderate correlation).

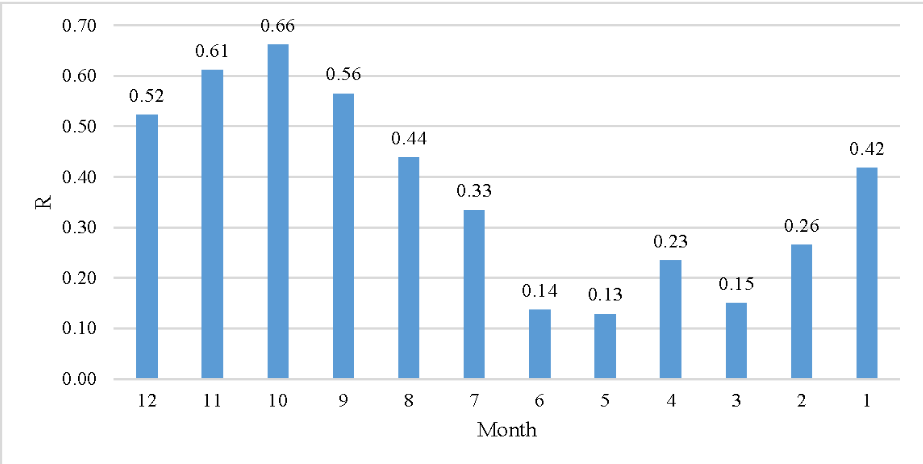

Fig. 3. Linear correlation between the intra-annual distributions of landslides and P(1)…P(12) in Georgia. Correlation coefficient values from 0.13 to 0.33 are negligible.

Fig. 3 also shows that a moderate correlation is also observed between the intra-annual distribution of LS with the intra-annual distributions of P(9), P(11), and P(12). For the pairs LS – P(1) and LS – P(1), the correlation is low. For the remaining cases, the correlation is negligible.

Linear regression equations between the intra-annual distributions of landslides (y) and P(1), P(8)…(P12), (x), in Georgia are as follows: P(1): $y = 0.3753x + 5.2062$; P(8): $y = 0.9013x + 0.8224$; P(9): $y = 1.2998x - 2.4986$; P(10): $y = 1.4601x - 3.8339$; P(11): $y = 1.3305x - 2.754$; P(12): $y = 1.0938x - 0.7817$.

Conclusion

In the near 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 using artificial intelligence methods in both steady-state and dynamic modes.

Acknowledgments

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მეწყრული განმეორების შიდა წლიური განაწილება საქართველოში და მისი კავშირი ნალექების ყოველთვიურ და კუმულაციურ მრავალთვიან ჯამებთან

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

რეზიუმე

შესწავლილი იქნა მეწყერების რაოდენობის (LS) წლიური განაწილების (%) და მეწყერის თვეში ნალექების რაოდენობის, ასევე მეწყერამდე ერთი თვისა და 1…11 თვით ადრე დაგროვილი რაოდენობის, შესაბამისად, P(1)…P(12) შორის კორელაციისა და რეგრესიის კავშირები. კერძოდ, დადგინდა, რომ საქართველოში მეწყერების წლიური განაწილება საკმაოდ არათანაბარია. მეწყერების ყველაზე დიდი რაოდენობა ივლისსა და სექტემბერში ხდება (შესაბამისად 11.7% და 11.0%), ხოლო ყველაზე მცირე - იანვარსა და ნოემბერში (შესაბამისად 5.3% და 5.6%). ზომიერი კორელაცია შეინიშნება LS წლიური განაწილებისა და წლიური განაწილების P(9)…(12) შორის. LS – P(1) და LS – P(8) წყვილებისთვის კორელაცია დაბალია. სხვა შემთხვევებში კორელაცია უმნიშვნელოა. წარმოდგენილია შესწავლილ პარამეტრებს შორის წრფივი რეგრესიის განტოლებები.

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

Внутригодовое распределение частоты оползней в Грузии и его связь с месячными и накопленными многомесячными суммами осадков

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Резюме

Изучена корреляционная и регрессионная связь между внутригодовым распределением (%) количества оползней (LS) и суммами осадков в месяце, когда произошел оползень, и накопленной сумме за месяц и 1…11 месяцев до оползня, P(1)…P(12), соответственно. В частности, получено, что внутригодовое распределение оползней по Грузии довольно неравномерно. Наибольшее количество оползней приходится на июль и сентябрь (11.7% и 11.0% соответственно), а наименьшее — на январь и ноябрь (5.3% и 5.6% соответственно). Наблюдается умеренная корреляция между внутригодовым распределением LS и внутригодовыми распределениями P(9)…(12). Для пар LS – P(1) и LS – P(8) корреляция низкая. В остальных случаях корреляция незначительна. Представлены уравнения линейной регрессии между исследуемыми параметрами.

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