Statistical Analysis of Extreme Mudflow Values and Their Return Periods in Namangan Region, Uzbekistan, 1995–2024

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Abstract. This study statistically evaluates the temporal variability, trends, extreme values, and return periods of mudflow events recorded in the Namangan region during 1995–2024. A total of 142 mudflow events were analyzed based on a 30-year time series. The Mann-Kendall test and Sen's slope estimator were employed to assess the temporal trend, while the Gumbel distribution was used to estimate extreme values. Extreme values corresponding to 2-, 5-, 10-, 20-, 25-, and 50-year return periods were calculated using the Gumbel distribution.
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Introduction. In recent years, climate change, an increase in extreme precipitation events, and growing anthropogenic pressure in mountainous areas, mudflows are one of the natural hazards in many mountainous regions of the world. In particular, in the mountainous and foothill regions of Central Asia and Uzbekistan, short-duration, high-intensity rainfall, rapid snow and glacier melt, and erosion processes on steep slopes can accelerate mudflow generation. Mudflows not only the contribute to the degradation of natural landscapes, but also cause substantial economic damage to settlements, transport infrastructure, irrigation networks, and agricultural lands.

One of the most important characteristics of mudflow events is their recurrence and extremity. In some years, mudflow events may not occur at all, whereas in other years, their number may increase several-fold. Such high variability makes it difficult to assess hazards based on simple mean values alone. Therefore, analyzing the temporal distribution of mudflow events using extreme value theory is of considerable scientific and practical importance, particularly for the design of engineering structures and the development of effective risk reduction measures.

Namangan region is one of the regions of Uzbekistan characterized by a high level of mudflow hazard. Mudflow events occur almost annually in the Kasansay, Chadaksay, Govasay, Podshootasay, Chartaksay, and other major and minor river basins originating in the Kurama and Chatkal mountain ranges. The highly dissected relief, steep slopes, and the predominance of short-duration, intense precipitation are among the main natural factors influencing the frequency and recurrence of mudflow processes in the region.

The object of this study is the mudflow events that occurred in the mountainous and foothill areas of Namangan region. The subject of the study is the statistical assessment of the annual frequency, extreme values, probability of occurrence, and return periods of mudflow events recorded in Namangan region.

The aim of this study is to statistically assess the temporal variability and extreme values of mudflow events recorded in Namangan region during 1995–2024, determine the probability distributions of annual mudflow frequencies, and estimate the frequency of mudflow events corresponding to 2-, 5-, 10-, 20-, 25-, and 50-year return periods based on extreme value theory.

METHOD AND METHODOLOGY

In general, various aspects of the Namangan region, including its natural conditions, population and economy, land and water resources, geosystems, and their anthropogenic transformation, have been investigated by O. Abdullayev (1995), A. Nazarov (2004), B. A. Kamalov (2007), A. S. Baratov (2007), O. M. Mirzamahmudov, K. M. Boymirzayev (2011), Y. I. Ahmadaliyev (2014), B. Kh. Kamolov (2018), U. N. Umurzakova (2021), M. R. Koriyev (2023), S. T. Abdurakhmonov (2023), M. Kh. Otamirzayeva (2025), H. N. Naimov (2025), V. I. Dergacheva (2025), and other researchers.

One of the important scientific studies carried out in the Namangan region is the research work of A. S. Baratov (2007) on the topic "Issues of organizing water management in the Namangan region and increasing its efficiency," which studied the region's water resources, their territorial distribution, and issues related to water management. This study is an important source for clarifying the hydrological conditions of the Namangan region and the geographical foundations of water resource use.

B. A. Kamalov (2007), within the framework of his doctoral dissertation on the topic "Active influence on hydrometeorological processes in Uzbekistan," carried out a number of scientific projects on hazardous hydrometeorological processes, the physical properties of precipitation, hail, and clouds in the Namangan region, as well as the organization of material and technical bases for services aimed at actively influencing hazardous hydrometeorological processes in the Chust, Kosonsoy, and Yangikurgan districts.

U. N. Umurzakova (2021), in her research work on the topic "Opportunities for optimizing the use of land and water resources in the Namangan region," analyzed the availability of land and water resources in the region, the territorial characteristics of their use, and existing problems. The study provides important proposals and recommendations on the management and use of water flows generated during mudflow events within the framework of water conservation and efficient use of water resources.

S. T. Abdurakhmonov's research (2023) focuses on the rational use of land and water resources in the Namangan region under climate change. The scientist paid attention to the effective use of mudflow waters in developing alternative methods of supplying agricultural crops with water under drought conditions, as well as to the impact of climate change on the water regime of rivers and streams.

V. I. Dergacheva (2025), in her doctoral dissertation "Unexpected mudflows in Uzbekistan: genesis, spatial and temporal distribution, natural disaster risk reduction," identified the characteristics and modern principles of the spatial and temporal distribution of sudden mudflows (the beginning, end, and total duration of the period of high mudflow risk, as well as the zones of formation, migration, and stagnation of mudflows) in the territory of the Republic of Uzbekistan. The research also identified periods of high mudflow activity in the administrative-territorial regions of Uzbekistan, in particular, in the mountainous and foothill areas of the Namangan region, and identified the watercourses where mudflow events are most common.

The analysis of the above studies shows that, to date, no research has been carried out in the Namangan region on the statistical assessment of the frequency, extreme values, probability of occurrence, and return periods of mudflow events.

The study of the recurrence of mudflow events in the Namangan region based on a 30-year data series observed during 1995–2024 allows for a quantitative assessment of the region's long-term mudflow activity. Based on annual mudflow events, the statistical characteristics of mudflow frequency over time and extreme values are assessed, and the probability of occurrence and return period are analyzed. This approach allows for a quantitative and statistically based assessment of mudflow risk in the Namangan region.

In preparing this research work, methods such as analysis of literature and archival materials, statistical analysis, mathematical modeling, historicism, observation, and field research were used.

DISCUSSION AND RESULTS

Namangan region is the largest region in the Fergana Valley of the Republic of Uzbekistan. Its area is 7.44 thousand sq. km. Namangan region is located in the east of the republic, in the northwestern part of the Fergana Valley, on the slopes of the Kurama and Chatkal mountains, branches of the Tien Shan mountain range. It borders Jalalabad region of the Kyrgyz Republic to the north and northeast, Andijan to the southeast, Fergana to the south, and Tashkent region and Sughd region of Tajikistan to the northwest. The main part of the region is located on the right bank of the Syrdarya River, in the wide Fergana Valley. The land surface is mainly flat, surrounded in the north by a series of hills and the Chatkal and Kurama mountains. The altitude is 350–800 m. Mountains and hills, mountain valleys, and oases were formed by the activity of large and small rivers and tributaries during the Quaternary geological period.

The region's climate is influenced by its location in Central Asia, its distance from the direct influence of the oceans, its surroundings by high mountain ranges, and radiation processes.

The climate is sharply continental. Summers are hot and long, and winters are short but relatively cold. The average annual temperature is +13 °C, dropping to −25 °C in January. In July, it reaches +35–45 °C. The growing season is 230–240 days. The amount of precipitation varies in different parts of the region, with an average of 230 mm, ranging from 90–190 mm in the western part of the region, 300–400 mm in the eastern part, and 600–1000 mm in the foothills. The bulk of the precipitation falls in spring and autumn (Fig. 1).

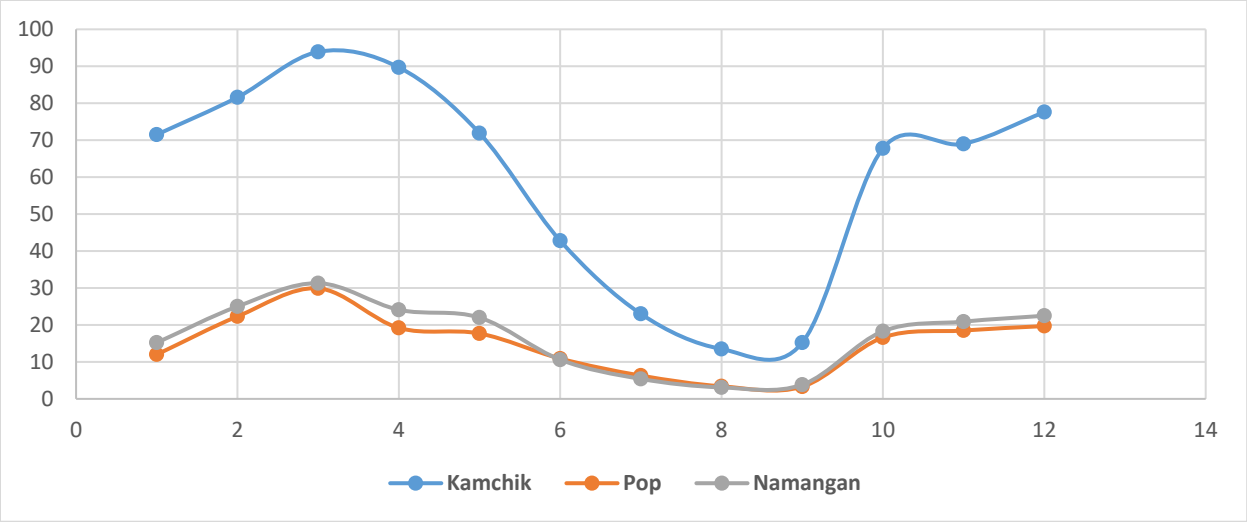


Fig. 1. Distribution of precipitation by month at meteorological stations in Namangan region

Rivers in the region receive water mainly from precipitation, snow, and glaciers in the mountains. There are 16 rivers and streams in the region, as well as many seasonal streams. The main hydrographic element is the Syrdarya, which is formed by the confluence of the Naryn and Karadarya rivers in the region. Among the local water sources, Kosonsay, Podshootasay, Govasay, Chartaksay, Chodaksay, and Namangansay occupy an important place.

Namangan region, due to its natural conditions, is one of the regions of Uzbekistan with a high risk of natural hazards. An analysis of various dangerous natural processes occurring in the region shows that, in terms of recurrence frequency and level of danger, mudflow events are the most active natural process. Mudflows not only cause natural emergencies of various scales and scopes in the region but also lead to tragic consequences associated with loss of life among the population (according to statistical data, the highest rates of deaths due to mudflows over the past 30 years have been observed in the Namangan region).

All mountainous and foothill regions of the Republic of Uzbekistan are included in mudflow hazard zones. Among the regions where such mudflows are most often observed, the mountainous and foothill areas of Namangan region stand out. Of the total 1,562 mudflow events that occurred in Uzbekistan in 1995–2024, 142, or 9.1%, occurred in Namangan region. The highest rates were observed in 1996 (29.7%) and 2020 (21%), while the lowest rates were recorded in 1997, 2001, 2005, 2006, 2009, 2012, 2013, 2014, and 2015 (0%). The share of Namangan region does not have a stable trend over time but is characterized by strong fluctuations (Fig. 2).

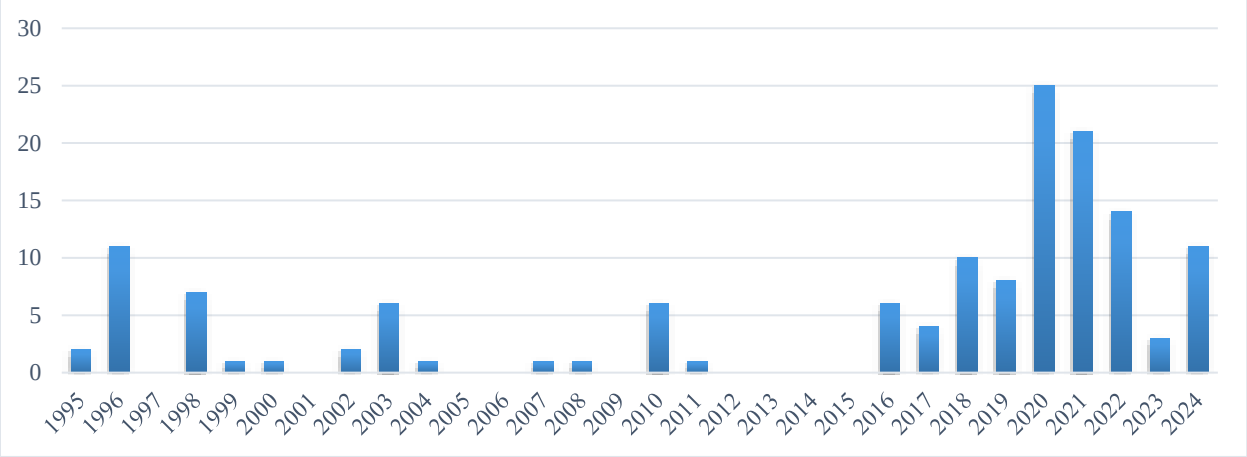


Fig. 2. Changes in the number of mudflow events in Namangan region between 1995 and 2024

A 30-year statistical series of mudflow events recorded in Namangan region during 1995–2024 was formed. A total of 142 mudflow events were recorded over the 30-year period. The number of annual mudflow events varied from 0 to 25, with an average annual value of 4.73 (Table 1).

Table 1. Main statistical indicators of mudflow events in Namangan region in 1995–2024

T/r	Statistical indicators	Value
1	Total number of mudflow events	142
2	Average annual value	4.73
3	Median	1.50
4	Minimum	0
5	Maximum	25
6	Range of variation	25
7	Standard deviation	6.41
8	Dispersion	41.10
9	Coefficient of variation	135.44 %
10	Coefficient of Skewness	1.80
11	Years without mudflows	9
12	Years with mudflows	21

As a result of assessing the variability of the statistical series of mudflow events for the period 1995–2024, the standard deviation was 6.41. The coefficient of variation of 135.44% indicates that the frequency of annual mudflow events has very high variability. The variance (41.10) is significantly higher than the average value (4.73), indicating an uneven distribution of annual events. In other words, in most years the number of mudflow events was relatively small, but in some years extreme values with very high frequencies were observed. In 9 years of the 30-year period, or 30% of the years, no mudflow event was recorded, while in 21 years at least one mudflow event was observed. This indicates that mudflow events in Namangan region are unevenly distributed over time and have a periodic character.

The Mann-Kendall test and Sen's slope trend line were used to assess the temporal trend of the mudflow event series for the period 1995–2024. Although the Mann-Kendall test showed a positive trend in the frequency of mudflow events, this trend was not statistically significant at the 5% significance level. The Sen's slope result showed an increasing trend of +0.143 mudflows per year. This indicates that the frequency of mudflow events has an increasing trend over time (Fig. 3).

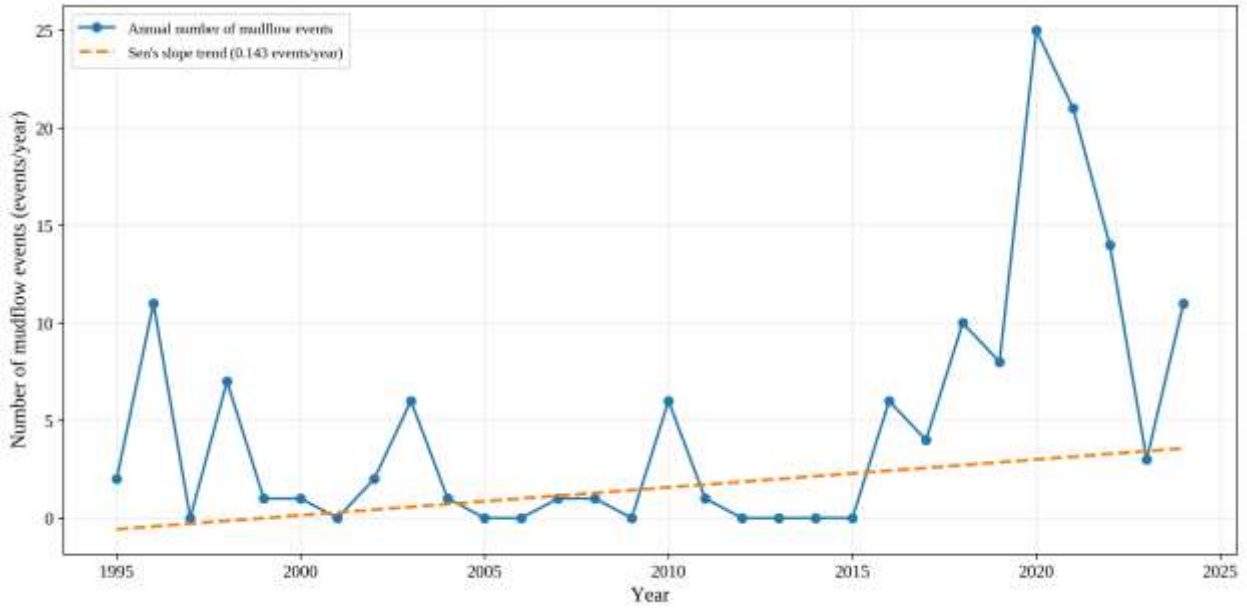


Fig. 3. Time series of mudflow events in Namangan region for 1995–2024 and Mann-Kendall trend

Analyzing changes in mudflow events over the years, as well as determining the probability of their recurrence and occurrence, is one of the important statistical approaches for assessing the risk of dangerous natural processes. Such indicators allow us to determine the recurrence patterns of mudflow events, assess the probability of their occurrence in the future, and characterize the level of risk on a scientific basis. The results of calculating the

return period are important for identifying areas with high mudflow risk, designing engineering structures, and dividing territories into regions according to risk level. Assessing the probability of mudflow events also helps prevent emergency situations, improve early warning systems, and develop effective measures for managing mudflow risks. Therefore, in this study, mudflow events that occurred between 1995 and 2024 were analyzed, and, in order to study their recurrence characteristics over a 30-year observation period, the return period and probability of occurrence of mudflows in Namangan region were calculated using the Weibull method, and the results were analyzed from the perspective of mudflow risk assessment (Table 2).

Formulas:

1) Return period

$$T = \frac{n+1}{m}$$

2) Calculation of the probability of occurrence

$$P = \frac{m}{n+1} \times 100 = \frac{100}{T}$$

Here

n = 30 (number of observation years)

m – rank in descending order of the number of mudflow events

Table 2. Main values of empirical return periods of mudflow events in Namangan region

m	Year	Number of mudflow events	Return period T (years)	Probability P (%)
1	2020	25	31.0	3.23
2	2021	21	15.50	6.45
3	2022	14	10.33	9.68
4.5	1996. 2024	11	6.89	14.52
6	2018	10	5.17	19.35
7	2019	8	4.43	22.58
8	1998	7	3.88	25.81
10	2003. 2010. 2016	6	3.10	32.26
12	2017	4	2.58	38.71
13	2023	3	2.38	41.94
14.5	1995. 2002	2	2.14	46.77
18.5	1999. 2000. 2004. 2007. 2008. 2011	1	1.68	59.68

The calculation results show that the most extreme mudflow activity during the observation period was observed in 2020, when 25 mudflows were recorded. The return period of this event is 31 years, and the probability of occurrence is 3.23%. This result indicates that it was the rarest and most intense event during the observation period. Next were the 21 mudflows observed in 2021, with a return period of 15.5 years and a probability of occurrence of 6.45%. The 14 mudflows observed in 2022 had a return period of 10.33 years and a probability of occurrence of 9.68%.

As a result of applying the average rank method, the 11 mudflow events observed in 1996 and 2024 had the same statistical value. The average rank for these events was 4.5, the return period was 6.89 years, and the annual probability of occurrence was 14.52%. Analysis of relatively low-intensity events shows that the return period for the 4 mudflows observed in 2017 was 2.58 years, while the 3 mudflows recorded in 2023 had a return period of 2.38 years. The average rank for the 2 mudflows observed in 1995 and 2002 was 14.5, their return period was 2.14 years, and the probability of occurrence was 46.77%.

In general, the results of the analysis indicate a clear hierarchy in the recurrence of mudflow events in Namangan region. Extreme mudflow events (14–25 events) are rare, and their return period varies between 10 and 31 years. Medium-intensity events (6–10 mudflows) can be repeated within 3–5 years, while low-intensity events (1–4

mudflows) are observed regularly within 1.7–2.6 years. This indicates that mudflow events in Namangan region recur periodically, but their intensity varies significantly from year to year.

The results of the empirical evaluation show that years with a high frequency of mudflow events recorded in Namangan region during the observation period are relatively rare. In particular, years with 20 or more mudflow events are very rare, which creates the need for separate statistical modeling of the distribution of extreme values.

At the next stage of the research, the Gumbel distribution was used to estimate the extreme annual values of mudflow events (Table 3).

The Gumbel distribution is based on extreme value theory and is used to statistically estimate extreme values, that is, the probability distribution of the largest or smallest values observed during a given period.

Table 3. Return values according to the Gumbel model

Return period T, years	Annual probability of exceedance, %	Gumbel return value. mudflow/year
2	50	3.54
5	20	7.73
10	10	10.49
20	5	13.15
25	4	13.99
50	2	16.59

According to the Gumbel results, the value corresponding to the 2-year return period is 3.54, the 5-year period is 7.73, the 10-year period is 10.49, the 20-year period is 13.15, the 25-year period is 13.99, and the 50-year period is 16.59. These results indicate that the frequency of extreme mudflows increases as the return period increases. In the time series for 1995–2024 formed for Namangan region, the 50-year return value is extrapolated beyond the observation period. Therefore, it is appropriate to interpret the 50-year value not as an exact forecast but as a statistical estimate based on the Gumbel model.

The Gumbel distribution provides a statistical basis for determining the 2-, 5-, 10-, 20-, 25-, and 50-year values of mudflow events in Namangan region, quantitatively assessing the level of extreme risk, and planning the area for risk resilience. At the same time, since statistical uncertainty in estimating 50-year return values based on a 30-year observation series may be high, future studies incorporating longer observation series, precipitation intensity, snowmelt, basin morphometry, and other hydrometeorological factors will make the results more reliable.

Conclusion. The main statistical indicators of mudflow events recorded in 1995–2024 and the results of the empirical assessment are very important for assessing mudflow risk in the mountainous and foothill areas of Namangan region, zoning hazardous areas, and use in engineering and territorial planning. This study helps determine the temporal variability and recurrence patterns of mudflow events in Namangan region by statistically assessing their multi-year dynamics and extreme values. The determined return values can be used in the design of hydraulic structures, the layout of road and railway infrastructure, territorial planning of settlements, and zoning of hazardous areas. In this regard, this approach has important scientific and practical significance for reducing economic and social losses caused by mudflow events in Namangan region and ensuring the sustainable development of the region.

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