Geojournal of Tourism and Geosites
ISSN 2065-0817, E-ISSN 2065-1198

Year XVIII, vol. 63, no. 4spl, 2025, p.2672-2678
DOI 10.30892/gtg.634spl12-1627

ASSESSMENT OF CLIMATE-RELATED LIMITING FACTORS IN A POPULAR TOURIST DESTINATION: CHARYN STATE NATIONAL NATURAL PARK, KAZAKHSTAN

Yuliya YUSHINA [1,2], Kamshat YEGEMBERDIYEVA [2*], Zhanerke SHARAPKHANOVA [1,2]

[1] Al-Farabi Kazakh National University, Faculty of Geography and Environmental Sciences, Almaty, Kazakhstan
[2] Institute of Geography and Water Security - JSC, Laboratory of Geotourism and Geomorphology, Almaty, Kazakhstan; yushinayukz@gmail.com (Y.Y.); kamshat.yegemberdiyeva @gmail.com (K.Y.); sharaphanova@gmail.com (Z.S.)

Citation: Yushina Y., Yegemberdiyeva K., & Sharapkhanova Zh. (2025). Assessment of climate-related limiting factors in a popular tourist destination: Charyn state national natural park, Kazakhstan. *Geojournal of Tourism and Geosites*, 63(4spl), 2672–2678. https://doi.org/10.30892/gtg.634spl12-1627

Abstract: The impact of certain meteorological phenomena may have a limiting effect on tourist activity. Temporal in situ measurements are valuable for understanding local climate characteristics when publicly available data provides generalized information at a large spatial scale. The study was conducted to determine and analyze the main weather extreme events that may disrupt tourism activity, as well as assess their spatial pattern across the Charyn State National Natural Park. The results of an assessment of climate-related limiting factors for the tourism sector were detected based on monitoring data collected by temporarily installed automatic meteorological stations. Archival data from the National Meteorological Service (Kazhydromet), along with remote sensing data, were also used to complement the analysis. The current research holds value by enhancing the general understanding of regional vulnerability disparities. The objective of the climatic impact-drivers concept is taken as a basis. In this context, the frequency of meteorological events was determined. Based on a weighted assessment of 11 meteorological parameters, considering their significance, an integrated hazard map was developed. The data indicates that the most vulnerable area is located along the Ulken Bugyty mountains and in the southern part of the Natural Park. The most frequently occurring event is very strong winds (24-29 m/s), particularly in the Ulken Bugyty mountains. A high recurrence of strong winds (15-23 m/s) is also observed on the "Valley of Castles" plateau, where the visitor center is located. The presence of the Ulken Bugyty mountains as an orographic barrier largely determines the spatial distribution of hazardous phenomena across the study area. The third decade of July is typically characterized by periods of 4-6 days with temperatures exceeding +35°C. In winter, fog is common in the northern part of the Charyn State National Natural Park. Conditions conducive to the formation of blizzards are rarely observed in the study area. The study also considers stakeholder parties in the tourism sector who are vulnerable to these hazardous phenomena.

Keywords: extreme event, climatic impact-driver, arid area, natural hazard, tourism

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INTRODUCTION

All sectors of the economy are affected by climate, though to varying degrees (IPCC, 2021a). For example, the impacts and risks associated with climate change for the tourism sector are considered moderate (IPCC, 2018b). However, it is important to note that increased risks are projected for seasonal tourism in specific geographic regions. Coastal areas and resorts that offer winter tourism are considered to be most vulnerable (Tourism & Climate Change, 2007; Mitrică et al., 2025). One of the adaptation strategies for the tourism industry is diversification of tourist destinations during the shoulder seasons (Gordon, 2023; Mitrică et al., 2025). The elevation zonality of Almaty region (Simbatova et al., 2020) enables diversification of tourist destinations during the shoulder seasons in the mountainous areas of Northern Tien Shan.

In spring, due to increasing avalanche risks and rapid snowmelt on trails in Ile Alatau (Blagovechshenskiy et al., 2017a, Blagovechshenskiy et al., 2023b), an alternative destination becomes the Charyn State National Natural Park (SNNP).

The concept of Climatic Impact-Drivers (CID) provides new perspectives on assessing climate assets (Higuera Roa et al., 2025) for different elements of society, ecosystems, economic sectors, and geographical areas (IPCC, 2021a). Climatic impact-drivers and their changes are climate conditions that can lead to positive, negative, inconsequential, or a mixture outcomes (Higuera Roa et al., 2025; IPCC, 2021a). Climate is not always a beneficial resource for tourist destinations. Extreme weather events played a crucial role in shaping travel preferences, with many of the respondents opting to avoid high-risk destinations (Özgit & Saleem, 2025). Earlier experience affected decisions not to return. Also, the impact of certain meteorological phenomena may have a limiting effect on tourist activity (Gómez Martín, 2005).

However, there is arguably also much evidence that even extreme events do not necessarily deter tourism for more extended periods (León-Cruz et al., 2025). Furthermore, specific meteorological characteristics may serve as essential

* Corresponding author

conditions for some tourist activities (Gómez Martín, 2005), for instance, strong winds for sailing and wind-based sports. Frequency of natural disasters and the level of vulnerability determine the number of publications for key study areas.

As a result, the most covered areas in literature are coastal and mountain regions. However, we should consider other popular tourist destinations in arid areas to understand the possibility of extreme events if we choose this destination as an alternative during the shoulder seasons. If unstable weather, avalanche danger reduces the duration of the favorable period in the mountain areas in the spring, other extreme phenomena affect the duration of the favorable season in other regions, for instance, heat in desert areas in the summer (León-Cruz et al., 2025). Identifying the list of extreme events within the specific research area (Mashula et al., 2025) and obtaining accurate knowledge of their annual frequency (Nhamo et al., 2025) is crucial for estimating the limitations imposed on tourism and recreational activities, as well as for assessing potential changes in the duration of the favorable season (Scott & Lemieux, 2010). The extreme weather disruptions at events can negatively impact tourism, as these incidents often lead to cancellations, reduced attendee numbers, and financial losses for destinations (McKinley et al., 2025). Furthermore, such information is essential for detecting the groups of stakeholders who may be affected by these reductions and should therefore be informed and involved in mitigation strategies (Scott & Lemieux, 2010; Mashula et al., 2025; Nhamo et al., 2025; McKinley et al., 2025).

The current study aims to determine and analyze the main weather extreme events that may disrupt tourism activity, as well as assess the frequency of each event and their spatial pattern on the Charyn State National Natural Park (SNNP). The objective of the climatic impact-drivers (CID) concept is taken as a basis. This provides a framework for adopting a more systematic approach to the identification and assessment of climatic factors (Higuera Roa et al., 2025).

Depending on the physical and geographical characteristics of the studied area, the list of unfavorable and hazardous phenomena varies. The Intergovernmental Panel on Climate Change (IPCC) report provides a list of weather and climate extreme phenomena relevant to key sector assets. Impacts and risk of CID are assessed in three categories, from “High” to “None/low confidence”. In arid areas, the main CIDs with high impacts and risk include the following groups: heat and cold, wet and dry, and wind (IPCC, 2021a). The studied area, Charyn State National Natural Park (SNNP), located 200 km from Almaty in a desert zone (Figure 1) the park is among the most popular tourist attractions in Almaty region (Bitter, 2023).

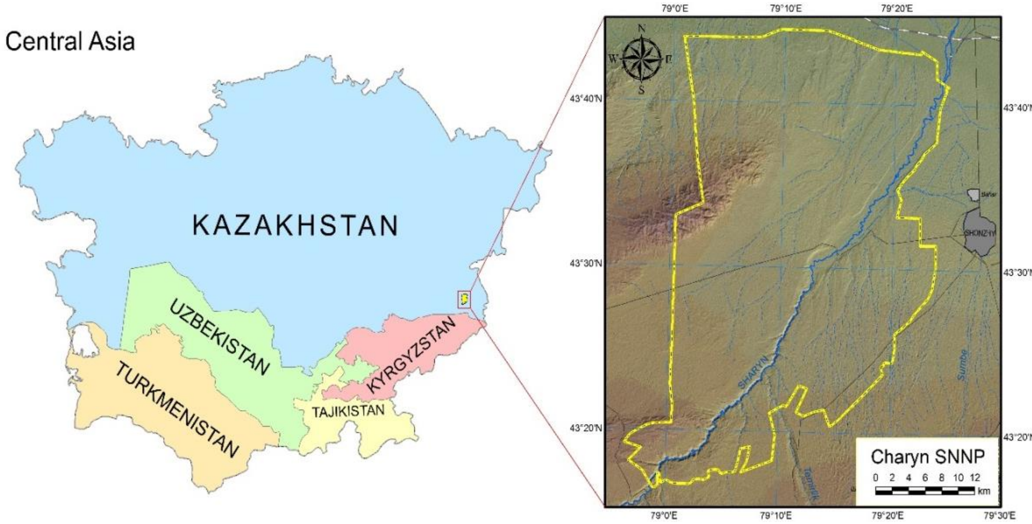

Figure 1. Schematic location map of SNNP Charyn. Source: Authors, based on ArcGIS Online (Countries in Central Asia and Caucasus Region, Global Administrative Areas); National Aeronautics and Space Administration Worldview (Global Digital Elevation Map, Color Shaded Relief)

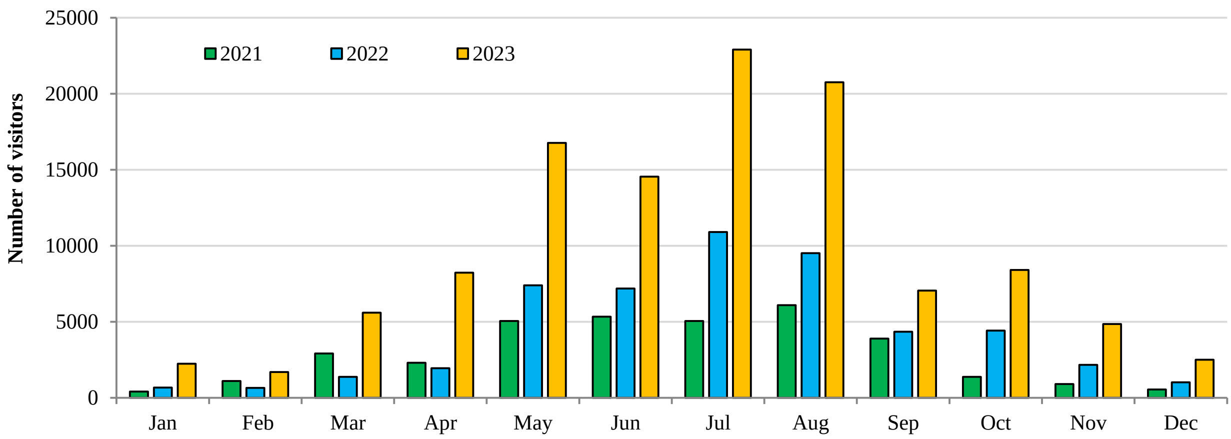

Figure 2. Visitor statistics in Charyn SNNP (Source: Official data provided by the park administration)

The territory of the Charyn SNNP covers 127,050 hectares, of which 49,248.9 hectares are designated for tourism and recreation activities. The park features four tourist routes with a total length of 30.5 km (Sharapkhanova et al., 2024; Nigmatova et al., 2021). According to the SNNP statistics, the number of tourists reached 115,569 in 2023, with the highest attendance in July – 2,909 visitors, Figure 2.

MATERIALS AND METHODS

The main objective of the study was to assess the Charyn SNNP's territory based on the frequency of hazardous and unfavorable meteorological phenomena, to facilitate the integration of these results with other factors (geological and geomorphological, hydrological, and biotic). This article presents a stage of the comprehensive assessment of the climatic factor. The study utilized archival data from National Meteorological Service (Kazhydromet) as well as monitoring data from temporarily installed stations within the Charyn SNNP. Data obtained during the monitoring period by the research team from October 2023 to April 2024 (automated meteorological stations (AMS): Ash Grov, Bugyty) were used.

The recurrence of atmospheric phenomena – such as fog (2022-2023), dust storms (2001-2023), blizzards (2012-2023), thunderstorms (1971-2000, and 2023), was evaluated based on climate data from the nearest stations of Shelek and compared with satellite imagery archived at https://worldview.earthdata.nasa.gov/ (corrected reflectance (Bands 7-2-1) Terra/MODIS), and view.eumetsat.int (Geostationary Ring Dust RGB – Multimission). At the initial stage, a list of potential unfavorable and hazardous meteorological phenomena within the Charyn SNNP was identified in accordance with the climate impact drivers (CID) groups (IPCC, 2021a; Gills et al., 2024; Ruane et al., 2022).

The hazard degree assessment was conducted based on criteria for meteorological hazard degrees in Kazakhstan, specifically considering temperature and wind. For precipitation, the likelihood was evaluated for intervals of 5.0-9.9 mm and exceeding 10 mm, reflecting the distinct physical and geographical characteristics and corresponding hazard criteria. As a result, the following list of unfavorable and hazardous phenomena for the Charyn SNNP was compiled, Figure 3.

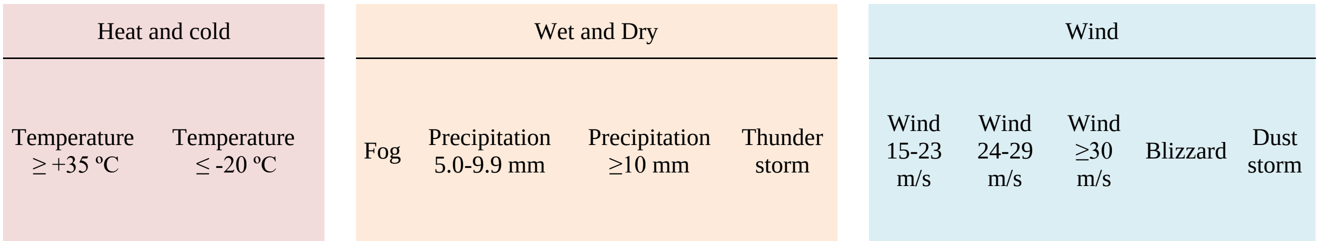

Figure 3. Adopted list of Climatic Impact-Drivers for Charyn SNNP (Source: IPCC, 2021a)

According to Formula 1 (Brier & Panofsky, 1958) and based on statistical analysis, the probability of occurrence for hazardous and unfavorable phenomena was determined.

$$P(E) = \left(\frac{f}{N}\right) \times 100\% \qquad (1)$$

Formula 1, where P(E) – the probability of event E, %; f – the number of cases when event E occurred; N – total number of observations (sampling size). The likelihood of each event was scored according to the criteria outlined in Table 1.

Table 1. Characteristics of probability estimates (Source: Tammepuu, 2008)

Characteristic	Probability, %	Score
Very Likely	≥50	5
Likely	≥5	4
Unlikely	≥0.5	3
Very unlikely	≥0.05	2
Extremely unlikely	≥0.005	1

Each phenomenon was assigned a significance level to prioritize the impact severity (Table 2, Formula 2). The significance was determined through expert judgment.

$$I_{CID} = \frac{\sum_{i=1}^{n} (C_i \times K_i)}{\sum_{i=1}^{n} K_i} \qquad (2)$$

Formula 2 (Clark-Carter, 2010) is a weighted mean, where I_{CID} – integrated index of meteorological hazard for point, *Ci* – probability score, *Ki* – significance score.

Table 2. Assessment of meteorological hazards (Source: Authors)

Parameter	Probability, score			Significance, score
	Charyn	Bugyty	Ash Grove	
Temperature ≥ +35 ºC	4	3	3	4
Temperature ≤ -20 ºC	3	3	3	4

Precipitation 5.0-9.9 mm	3	0	4	4
Precipitation ≥10 mm	2	4	3	5
Wind 15-23 m/s	3	2	0	4
Wind 24-29 m/s	3	3	0	5
Wind ≥30 m/s	0	3	0	5
Fog	4	4	4	3
Blizzard	2	2	2	4
Dust storm	2	2	2	4
Thunder storm	3	3	3	5

RESULTS

Precipitation of ≥10 mm, thunderstorms, and wind (24–29 m/s, ≥30 m/s) hold the greatest significance, scoring 5 points, for the area under study. Excessive precipitation can act as a trigger for hydrological and geomorphological processes, while wind significance is assigned based on the severity of the phenomena's hazard to Kazakhstan and their likely consequences, according to the Beaufort scale. Based on a scoring system of 11 meteorological parameters, taking their significance into account, a hazard map for meteorological phenomena has been developed for the Charyn SNNP, Figure 4. The data indicate that the most vulnerable area is along the Ulken Bugyty mountains and the southern part of the Charyn SNNP.

According to the assessment of hazardous and unfavorable phenomena within the Charyn SNNP, it can be noted that the most frequently occurring event (Figure 4) is very strong winds (24-29 m/s) – particularly in the Ulken Bugyty mountains. A high recurrence of strong winds (15-23 m/s) is also observed in the area of the Charyn AMS on the "Valley of Castles" plateau, where the visitor center is located.

During winter, the northern part of the SNNP is characterized by fog. Squalls and hurricane-force winds are typical for the Ulken Bugyty mountains, along with precipitation exceeding 10 mm. The recurrence of extreme temperatures is observed throughout the area, ranging from about 4 days in the cold season (temperatures below -20°C) to approximately 11.5 days for temperatures above +35°C. The probability of dust storms and blizzards is low. Conditions necessary for blizzards formation are rarely met within the Charyn SNNP. Given the high frequency of very strong winds at the Bugyty AMS, snow whirlwinds may occur on the windward western slopes of the Ulken Bugyty mountains under such conditions. The presence of orographic barrier largely determines the spatial distribution of hazardous phenomena across the study area.

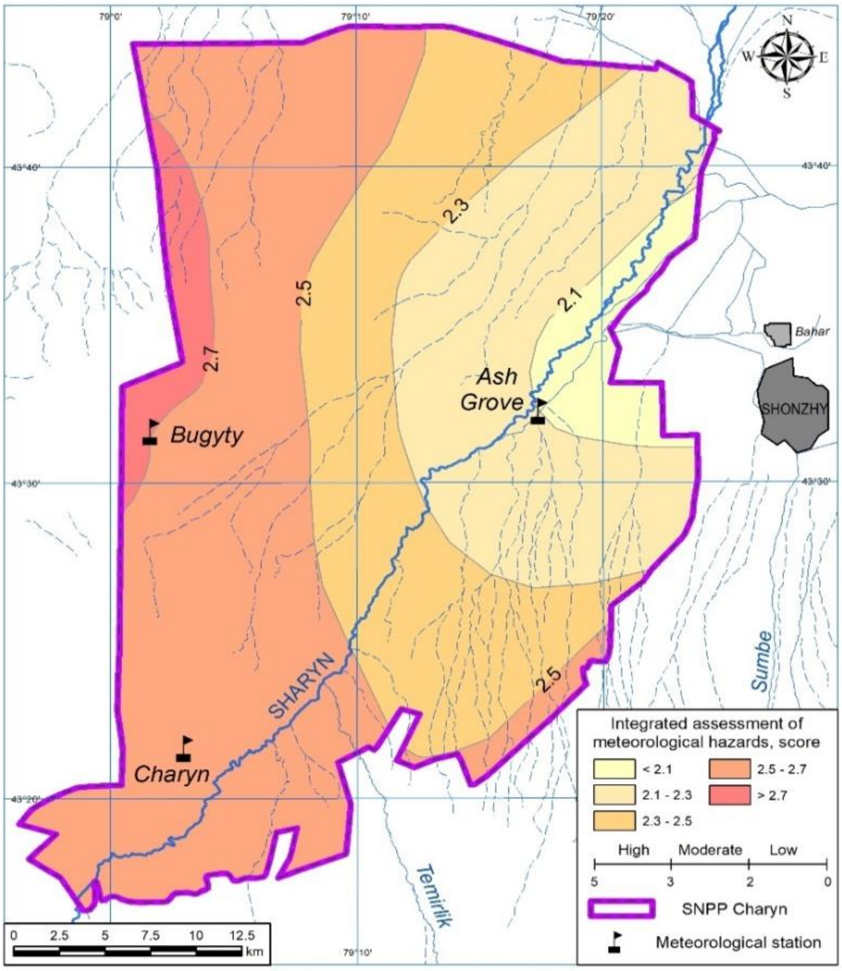

Figure 4. Integrated map of spatial distribution of meteorological hazard (Source: Authors)

DISCUSSION

We can divide two groups of stakeholders who could be impacted by unfavorable events and hazards: Government and Tourism industry, Figure 5. All stakeholders could be divided into these two types: those who are more involved into ecosystem services and others who have any type of infrastructure objects. Tour operators would be a category, which depends on those two groups of stakeholders. Regarding tourists, guides and transport, they directly depend on weather conditions but are more adaptive and flexible to season changes and can change the destination at the stage of planning, unlike holders of tourist infrastructure. Extreme weather events can damage or destroy infrastructure, leading to delays, cancellations, and increased maintenance costs (Gössling & Scott, 2025).

In this case we divided tourism industry into two types of stakeholders: geographically fixed and mobile groups. Tourism industry represents part of the economic system, developed for promoting social and mental well-being based on natural resources, influenced by changes in climate conditions. Government is one of the stakeholders interested in sustainable development of region and economic grow. Development of tourist industry, on one side, depends on policy documents and programs issued by government which could be the reason for choosing location for resort planning.

Also, decisions in emission reduction responsibilities, land use planning, disaster risk management could be managed by the government (Figure 5). For this reason, the Government in framework should be presented by policy as actor of decision making. Specially Protected Natural Areas are presented as stakeholders directly linked to government. Physical climate risks encompass extreme weather, biodiversity loss, and health risks. Socio-economic impacts involve social disruptions and changes in economic opportunities and employment (Gössling & Scott, 2025).

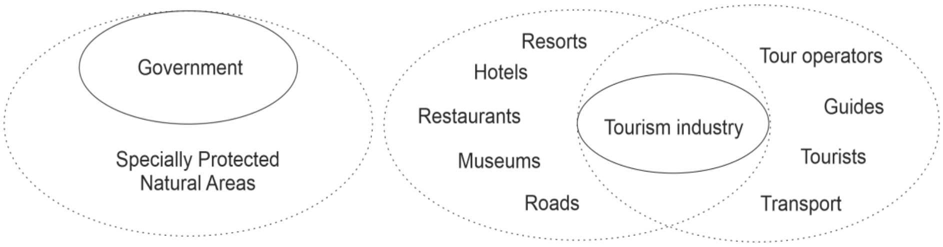

Figure 5. Groups of stakeholders (Source: Authors)

We can talk about cancellation ratio in context of tour or hotel bookings (Falk & Hagsten, 2017). In this case, cancelation ratio is more frequently the result of extreme events and less of changes in seasonality. On high favorable season if guides work every weekend, the loss of income could be about 10-20% in case of the 1-2 days tour cancellation.

Natural hazards may impact directly on local level in short-term perspective on infrastructure by destroying it. Charyn SNNP is more frequently affected by a road washout due to mudflow (Sharapkhanova et al., 2024). At the same time impact could be on ecosystem components and recovery of it would be prolonged to long-term. At the local level, natural hazards influence the spatial distribution of tourists and population density (Keiler et al., 2005). In short-term perspective, natural disasters could be the main migration force, but can also interact with other factors (Khatib, 2023).

CONCLUSION

For the assessment of each hazardous and unfavorable meteorological phenomenon or process, threshold values are established. For the Charyn SNNP, certain parameters, such as precipitation, have been taken into account due to their infrequent manifestation. The assessment results indicate that the highest recurrence is observed for very strong winds (24–29 m/s) and strong winds (15–23 m/s) across the study area. Although fog is frequent, the overall risk is reduced during the winter months when park visitation decreases (Figures 2, 6).

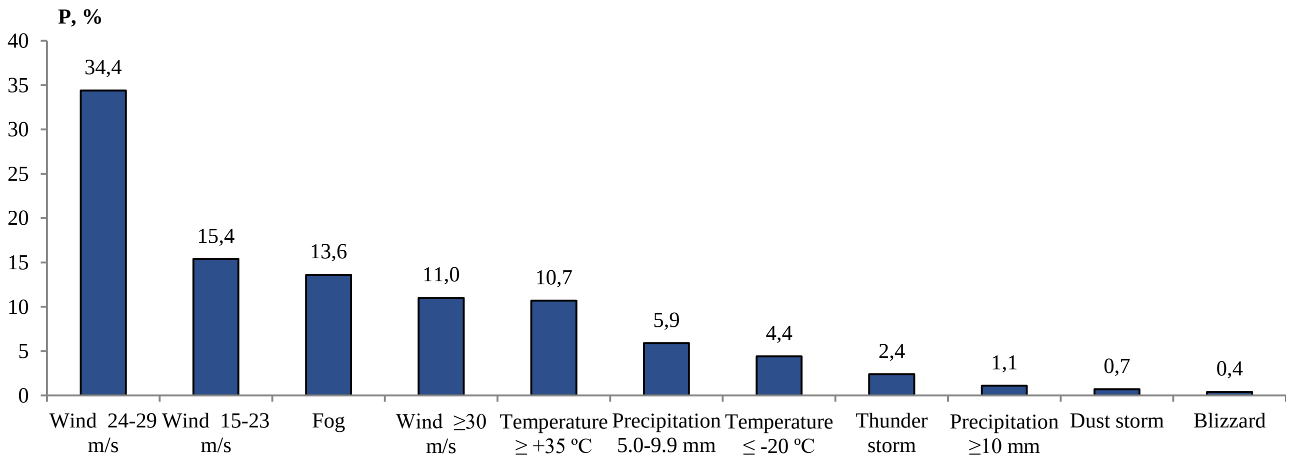

Figure 6. Maximum frequency of meteorological events for the Charyn SNNP (the total number of all events is taken as 100%) (Source: Authors)

During spring and summer, particular attention should be paid to weather forecasts for precipitation, as secondary hydrological and geomorphological processes tend to become more active during this period. Squalls and hurricane-force winds are characteristic of the Ulken Bugyty mountains, along with precipitation exceeding 10 mm. In the third decade of July, periods of 4 and 6 days with temperatures exceeding +35°C were observed in 2022 and 2023.

This can be explained by the dominance of a summer thermal depression over Central Asia and south of Kazakhstan, which most often reaches its peak development around this time. In 2022 and 2023, July ranked first, and August is second in visitation, as shown in Figure 1, indicating that increases in temperature are not significantly taken into account by visitors. The results of the study allowed for a more precise understanding of the spatial distribution of extreme meteorological phenomena within the Charyn SNNP and their recurrence in relation to other weather events.

Author Contributions: Author Contributions: Conceptualization, Ye.K.; methodology, Y.Y.; software, Sh.Zh.; validation, Ye.K. and Sh.Zh.; formal analysis, Y.Y.; investigation, Y.Y.; data curation, Y.Y.; writing - original draft preparation, Y.Y.; writing - review and editing, Ye.K. and Sh.Zh.; visualization, Sh.Zh.; supervision, Ye.K.; project administration, Ye.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, grant №AP19677559 “Instrumental and methodological assessment of hazardous natural phenomena and processes of the Charyn State National Natural Park”. The APC was funded by the same grant.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study may be obtained on request from the corresponding author.

Acknowledgements: The authors express their gratitude to the staff and administration of the Charyn State National Natural Park for their valuable support during field works arrangements.

Conflicts of Interest: The authors declare no conflict of interest.

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Article history: Received: 23.06.2025 Revised: 02.11.2025 Accepted: 29.11.2025 Available online: 31.12.2025