THE IMPACT OF EXTREME RAINFALL FOR A CRUISE IN THE PUNKVA CAVES

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Abstract
The influence of weather on outdoor recreation is clear. However, the development of the climate brings an increased frequency of extreme manifestations of meteorological elements. Their negative effects also affect the possibilities of recreation not only in the open countryside, but also in caves. The evidence is the closure of the Punkva caves in the Moravian Karst, due to high rainfall totals. The occurrence of extreme precipitation in summer and early autumn had catastrophic consequences on our territory. The sailing of the electric boat in the Punkva caves was affected, it was completely closed after the floods, and then limited in October. Closed again in January and February due to damage to the electrical installation. There was a significant rise in the level of the Punkva River, layers of mud were deposited in the cave environment, and the electrical installation was damaged. The cause was exceptionally high rainfall totals between September 14 and 16, when daily rainfall totals exceeded 60 mm. However, as far as the Moravian Karst area is concerned, part of the caves were already affected by floods in July. From the point of view of the provision of recreation, it appears that the extremes of the weather will affect it more and more. It will be necessary to create specific forecasts of the occurrence of weather extremes in this area as well.

Key words: precipitation, recreation, Moravian Karst, flood

Úvod

Moravian Karst is a very interesting tourist area, thanks to the unique living and non-living nature of the karst region, which is mostly covered by forests. This is due to the fact that it is formed from limestones dating from the Middle Devonian to the Late Carboniferous. There are more than 1,100 caves here, five of which are open to the public: Balcarka Cave, Kateřinská Cave, Sloupsko-Šošůvka Caves, Výpustek Cave, and the Punkva Caves. In addition to viewing the stalactite decorations, the Punkva Caves also offer the possibility of a boat ride along the underground section of the Punkva River. Amateur speleologists, however, enter some of the caves that are not open to the public. The largest cave system among these is the Amatérská Cave, which is over 40 km long. Twenty-one species of bats and horseshoe bats live in the caves. The Moravian Karst also has numerous archaeological and paleontological sites (Musil et al., 1993).
The visit to the Punkva Caves is linked to the research of Professor Karel Absolon at the beginning of the 20th century, who organized several descents with multi-day stays for entire groups of researchers. Absolon's research at the bottom of the Macocha Abyss gradually led him to the discovery of the Punkva Caves and the Macocha Water Domes—spaces traversed by the active Punkva River. The current tour route through the Punkva Caves (Fig. 1) has a "dry" and a "water" section. The entrance to the caves is from the Pustý žleb valley through a tunnel that was blasted through the rock for this purpose. Visitors pass into the Front Dome past the Guardian, a 4-meter-long stalactite. Then they cross a bridge, from which they can see the extensive decorated wall of the Front Dome and the largest stalactite in the Punkva Caves, the so-called Salm Column. The original siphon, the lowest dry spot in the Punkva Caves, which was often flooded in the past, is now passable thanks to modifications. Its water level is automatically regulated by a pump. Given the focus of our study, it is necessary to point out the signs with the years 1914 and 1938 in the Reichenbach Dome, which indicate the highest level of the Punkva during the floods of those years. After a long staircase, visitors ascend into a massive space several tens of meters high. Through the Stalagmite Corridor, visitors proceed to the Rear Dome, from which they descend by stairs into the Hall by the Angel and again through an artificial tunnel down to the bottom of the Macocha Abyss. At the bottom of the abyss is the so-called Dead Channel, through which, during high water levels, the Punkva flows from the Pre-Macocha Siphon from the Amatérská Cave.
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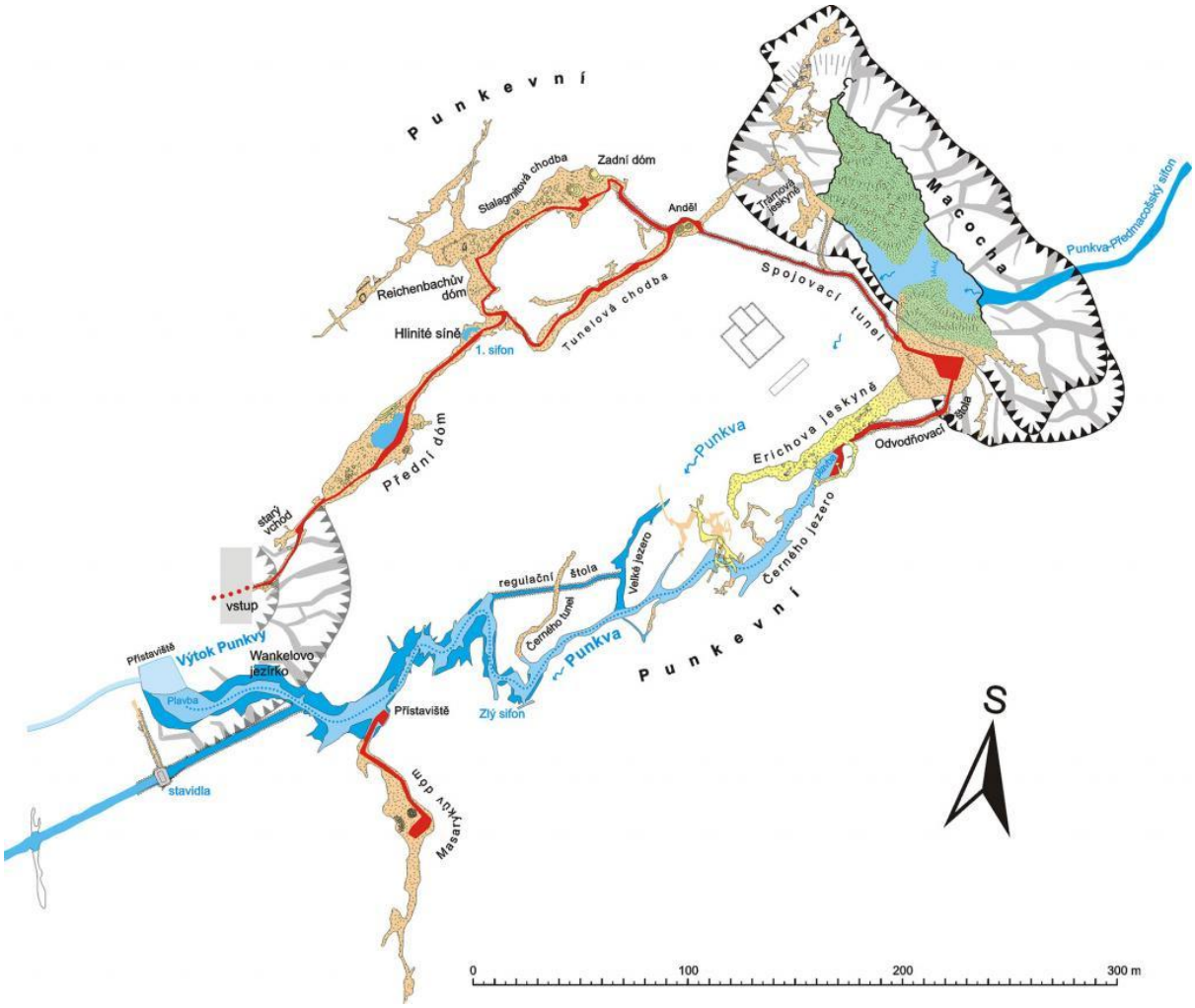

Fig. 1: Punkva Caves

The "water section" begins with a corridor leading to the dock, that is, a boat ride on motorboats. The journey starts along a blind arm of the Punkva River, passing high chimneys to the so-called "Čtyřicítka" (The Fortieth). From there, the ride continues on the active stream, as the Punkva emerges deep below the surface into open spaces. After sailing through the Fairy Tale Lakes, the underground boat ride is interrupted at the dock for a tour of the next part of the cave, including the Masaryk Dome, which features the most impressive stalactite formations. The boat ride then continues to the Punkva spring, where it ends. A more detailed description can be found on the website https://punkevni.caves.cz/.

As already mentioned, although it is rare, flooding in the Punkva Caves can cause the water level to rise so significantly that boat rides become impossible. The occurrence of floods is caused by exceptionally high rainfall, which, according to various studies, is expected to become increasingly frequent.

For evaluating our climate, sources are available in the Atlas of the Climate of Czechoslovakia (1958) and Climate of the Czechoslovak Socialist Republic – Tables (1960), which present data processed for the period 1901 to 1950. Maps of climate elements in the Atlas of the Climate of the Czech Republic (2007) were created from meteorological data for the period 1961 to 2000. However, these climatological sources no longer correspond to at least the last 20 years, due to ongoing climate change.

The variability of our climate is determined by the geographical location and the relief of our territory. We are part of the temperate climate zone, but in the area of a transitional Central European climate. Circulation and geographical conditions play a significant role. For most of the year, temperate air masses prevail here, but for short periods, tropical air masses as well as arctic air masses can also affect our territory.

Unlike air temperature, precipitation may slightly decrease according to some authors (Střeštík et al., 2014). Kożuchowski and Marciniak (1990) presented a study showing that in Western and Northern

Europe, precipitation has recently been increasing and will continue to do so, while in Southern and Eastern Europe, it has been decreasing and will continue to decrease. Our territory lies in the area of expected decline. This trend has also been confirmed by more recent research. For the territory of the Czech Republic, atmospheric precipitation is the only source of water, but its occurrence is changing, with more frequent torrential rainfall alternating with longer dry periods (Rožnovský, 2019). This trend was confirmed by the weather patterns of 2024. Evidence of the extremity of our weather is the radical changes in September 2024, when, over four days of exceptionally high rainfall totals, there was also a rapid change in air temperature. Days of tropical temperatures without precipitation were replaced by a cooling of more than twenty degrees. Exceptionally high rainfall caused even extreme floods.

Methodology

The evaluation of precipitation patterns is based on meteorological measurements from climatological stations of the Czech Hydrometeorological Institute (hereinafter ČHMÚ) in 2024. Given the occurrence of exceptionally high rainfall totals in September, an assessment of monthly totals was carried out for the entire territory. With regard to the situation in the Punkva Caves, daily precipitation measurements from the ČHMÚ rain gauge station in Sloup were evaluated. Standard statistical processing methods were used.

Results

On the website of the Cave Administration of the Czech Republic (https://punkevni.caves.cz/), the following announcement is posted: “From Monday, February 17, 2025, the Punkva Caves are, for technical reasons, without boat rides until further notice. After touring the dry section from the bottom of the Macocha Abyss, visitors return via the Tunnel Route, which is otherwise not accessible to the public.

“Visits to the Punkva Caves were also without boat rides on the dates June 22–23, 2025, June 24–25, 2025, and September 15–21, 2025. Visitors surely wondered why. The answer lies in the exceptionally high rainfall. Let’s therefore take a look at the occurrence of precipitation in 2024, which had an above-average annual total.”

In every climatological assessment of precipitation occurrence in our territory, it is stated that precipitation is variable, both over time and in space. Their occurrence so far this year has not only confirmed this but has been even more dynamic than usual. Precipitation was highly variable even within individual months of this year, and in terms of spatial distribution, its occurrence was exceptionally uneven. In January, the monthly total corresponded to the norm, with flood situations continuing in the first decade of the month as a result of accelerated snowmelt following December 2023. The last winter month, February, had above-normal precipitation. Overall, it amounted to 150% of the norm for the period 1991 to 2020. Again, it should be emphasized that the winter of 2023/2024 was abnormally warm, by 2.4 °C. Since 1961, it was the second warmest after the winter of 2006/2007 (+2.7 °C). The winter of 2023/2024 had a total precipitation 200 mm higher than the norm and had the highest winter precipitation total since 1961.

Winter was followed by a precipitation-normal March, though with significant regional differences. In Bohemia, there were stations with a monthly total of less than 10 mm of precipitation. Similarly, April had normal precipitation totals, but again with large regional differences. Interestingly, in the second half of the month, there were still some occurrences of snowfall, which was related to a brief cooling caused by inflows of air from the north. In contrast, May had above-normal precipitation, but again with a very uneven distribution. Most of the precipitation fell in the last decade of May. From this perspective, spring precipitation can be described as normal, but with very significant regional differences.

The beginning of summer, that is, the month of June, continued with “normal” precipitation totals, but again with large differences across our territory. The highest totals were in Moravia, while on the Czech side there were more places with monthly precipitation totals up to 50 mm. The Moravian Karst area was among those that experienced exceptionally high daily totals. As we can see from the daily precipitation records at the Sloup station (Fig. 2), on June 15 the daily total was 35.5 mm, but on June 21 it was as much as 68 mm. This rainfall was the reason for the subsequent suspension of boat rides due to disruption of installations.

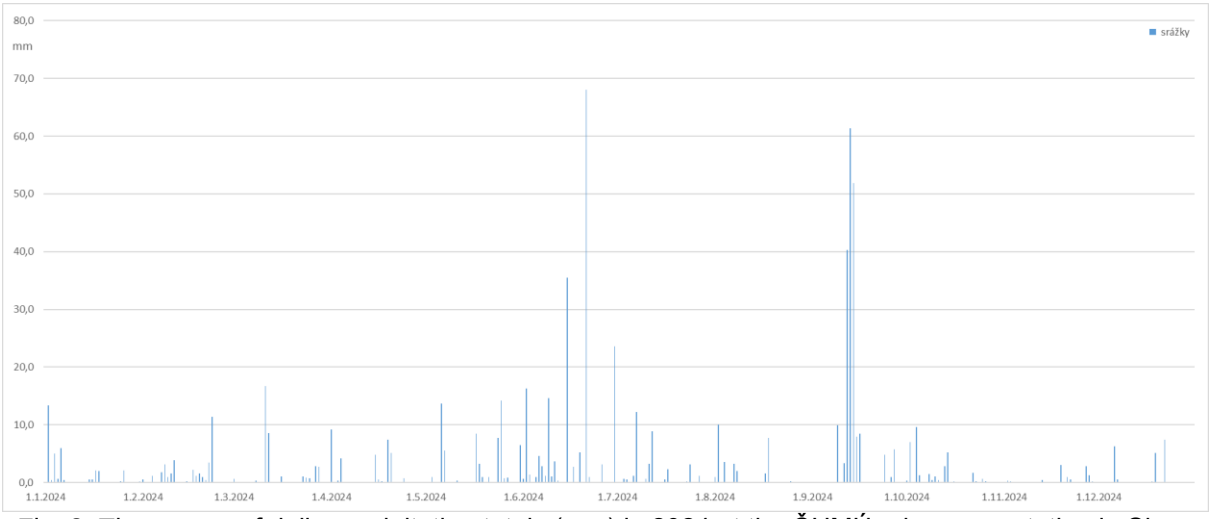

Fig. 2: The course of daily precipitation totals (mm) in 2024 at the ČHMÚ rain gauge station in Sloup

Traditionally, July is the month with the highest long-term precipitation totals, but this year the totals were overall normal. In general, more precipitation fell in Bohemia, while lower totals were recorded in Moravia and Silesia. It should be added that in many places, July's precipitation was of a stormy nature, including local occurrences of hail, which caused subsequent damage to crops.
Special attention should be paid to the course of precipitation in September, especially in its second decade. In many places in our territory, by September 8, not even 80% of the 1991–2020 normal had fallen. However, as we can see in Fig. 2, during the week from September 9 to 15, 2024, the situation changed radically. As a result, September had exceptionally above-normal precipitation, with an average monthly total for the entire territory of 179 mm, which is 298% of the normal. This meant that many previous records were broken. It was the highest September total and the second highest monthly precipitation total in the Czech Republic since 1961. Moreover, such a high percentage of the normal (298%) has not been recorded for any month since 1961. Of course, there were also large regional differences. It is important to emphasize that this precipitation essentially fell within just four days. In the Moravian Karst area, there was a rainless period from August 19 to September 8, 2025. And, as in most of our territory, from September 9 to 17, 2025, the total precipitation was 183.5 mm, which is a third of the average annual total.
For a complete overview, it should be noted that the highest daily precipitation total ever recorded was surpassed when, on September 14, 385.6 mm was measured at the Loučná nad Desnou, Švýcárna station (Šumperk district). Until now, the highest daily total was 345.1 mm (Bedřichov, Nová Louka, July 29, 1897).

Conclusion
The overview of precipitation occurrence demonstrates its great variability both over time and across regions. We can say that both the June precipitation and the extremely high totals in September were truly exceptional. However, in the future, we must expect an increase in extreme precipitation events. At the same time, it should be noted that during the summer, especially in August, much of our territory experienced drought. This situation in the landscape limits infiltration and increases the proportion of surface runoff.
Extreme precipitation events are caused by rising air temperatures, which allow the air to hold much more water vapor, leading to the formation of massive cloud systems. Extreme manifestations of air temperature and precipitation will logically affect recreational opportunities.

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Souhrn
Rozvoj rekreace v přírodě je závislý na průběhu počasí. Zvláště extrémní projevy jsou často limitujícím faktorem pro pobyt v přírodě. Průběh počasí, zvláště srážek v roce 2024 ukázal na velká nebezpečí, která představují mimořádně vysoké srážky. Kdy zcela mimořádné denní úhrny mezi 9. až 16. zářím měly katastrofální následky. Přitom je nutné kalkulovat s doprovodnými projevy extrémních srážek, jak dokládá zastavení plavby v Punkevních jeskyních. Vysoké denní úhrny intenzivních srážek zvedly hladinu Punkvy tak, že došlo k narušení instalací na plavební cestě a několikanásobnému zastavení vodní plavby. Podle dosavadního vývoje i scénářů změny klimatu budou extrémní projevy počasí častější.

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