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Dependence between length and size of design precipitation

(Závislost mezi délkou a velikostí návrhové srážky)

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Abstract: In the frequency analysis of precipitation totals with variable precipitation accumulation duration, we found that the function describing the relationship of the design precipitation totals on the logarithm of the length of the considered time window has a wavy shape. The shape is obviously related to the fact that extremes for different time periods have different causes. The relative slowdown of the increase in design totals with increasing precipitation duration occurs for the duration of approximately three hours and three days, which we explain by the limited duration of convective storms and cyclones causing extreme stratiform precipitation, respectively.

Keywords: design precipitation – DDF curve – convective and stratiform precipitation

Abstrakt: Při frekvenční analýze srážkových úhrnů s proměnnou délkou akumulace srážek jsme zjistili, že závislost úhrnů návrhových srážek na logaritmu délky uvažovaného časového okna má zvlněný tvar. Tato skutečnost zjevně souvisí s tím, že extrémy za různě dlouhé časové úseky mají odlišnou příčinu. Relativní zpomalení nárůstu návrhových úhrnů s rostoucí délkou srážky nastává u délky cca tři hodiny a znovu pak u délky cca tři dny, což vysvětlujeme omezenou dobou trvání konvektivních bouří, resp. cyklon vyvolávajících extrémní stratiformní srážky.

Klíčová slova: návrhové srážky – DDF křivky – konvektivní a stratiformní srážky

Introduction

For water management purposes, it is essential to know heavy rainfall statistics at a given location. To present statistics of abnormal precipitation, the relationship between duration (more precisely, the length of the considered time interval) and precipitation depth or intensity is usually expressed by depth-duration-frequency (DDF) or intensity-duration-frequency (IDF) curves, respectively. An individual curve characterizes a certain probability level and can be used to determine how much precipitation falls in a given location during a given time interval on average once in a given return period. The DDF and IDF curves increase and decrease, respectively, as the total precipitation generally increases, and its mean intensity decreases with increasing duration.

The primary goal of constructing both DDF and IDF curves is to establish a continuous and monotonic relationship between accumulation duration and return levels of precipitation totals/intensities (design precipitation) for a given return period. The construction process generally consists of two steps: (i) estimating design precipitation totals/intensities for selected time intervals and (ii) fitting these values to an empirical function to generate a smooth curve.

A significant advancement in IDF and DDF curve modelling was introduced by Koutsoyiannis et al. (1998). Their rigorous IDF formula was built on a generalized formula that encapsulates insights from preceding traditional IDF studies. They developed a probabilistic framework that is consistent with extreme value theory and the scaling behaviour of rainfall intensity with duration. They derived the specific functional form of the IDF relationship using the underlying theoretical distribution of maximum intensities and employed robust statistical techniques for parameter estimation. Their formulation was validated using real data from a large region of Greece, demonstrating its reliability and applicability, including its ability to incorporate data from nonrecording stations. However, their approach assumes that the parameters governing the scaling behaviour of rainfall intensity with duration remain constant.

The aims of this paper are (i) to demonstrate the limits of constructing DDF curves for a wide range of rainfall durations using the approach introduced by Koutsoyiannis et al. (1998), hereafter referred to as the standard approach; (ii) to present a novel approach using polynomial functions; and (iii) to explain the suitability of the novel approach by analysing rainfall intensities within a set of rainfall events.

Data and methods

The issue is presented on data from the Czech weather station Tábor (467 m a.s.l.), data period is 1951–2022. Annual rainfall maxima are selected within sliding time windows ranging from 2 minutes to 96 hours. The maxima for a specific length of time are then fitted by the GEV function (Coles 2001), employing the L-moment-based index storm procedure (Hosking and Wallis 1997). To improve the fit for individual stations, sample L-moments are adjusted by the region-of-influence (ROI) method introduced by Burn (1990). The ROI method utilizes statistically homogeneous pools of stations, in which all regional data, weighted by a dissimilarity measure (i.e., by geographical distance), are used for estimating the GEV distribution parameters at the station of interest. The derived parameters are used to determine design rainfall totals for 25 different durations independently.

DDF curves are then constructed for each return period to identify a suitable approximation of the relationship between the duration and magnitude of the design precipitation. First, the standard approach with a three-parameter function is used to estimate the design rainfall intensity

$$I_N = \frac{\mathrm{a}}{(c+d)^b}, \qquad (1)$$

where I_N is the design precipitation intensity [l·s^{-1}·ha^{-1}] with a return period of N years; d is the duration [min]; and a, b, and c are parameters specific for individual stations and return periods derived by the least squares method using a modification of the Levenberg-Marquardt algorithm (Moré 1978). Next, the design precipitation intensity I_N is transformed to the corresponding design precipitation total

$$R_{dN} = \frac{60\, I_\mathrm{N}\, d}{10000}, \qquad (2)$$

where R_{dN} is the design precipitation total [mm] with duration d [h] and return period N years.

The fact that standard DDF curves fit the estimates only within a limited range of durations motivated us to search for another theoretical function. Obviously, this function needs to be characterized by more than three parameters. Since the dependence of the design precipitation on the logarithm of the duration has a shape resembling a series of symmetrical waves, we decided to apply a polynomial function, namely, of the sixth degree

$$R_{dN} = p_N(\log d)^6 + q_N(\log d)^5 + r_N(\log d)^4 + s_N(\log d)^3 + t_N(\log d)^2 + u_N(\log d) + v_N, \quad (3)$$

where R_{dN} is the design precipitation total with duration d [h] and return period N years, and p, q, r, s, t, u, and v are parameters specific for individual return periods.

Results

To construct DDF curves, design totals are considered as a function of the precipitation duration for each return period independently. Because design totals are estimated only for a limited number of durations, the dependence is described by a series of individual values. It is clear from Fig. 1 that the shape of the dependence of the design total on duration is quite complex. In general, the growth of the design totals naturally slows with increasing duration. This weakening of growth is relatively slow on the order of tens of minutes. For durations from ca 10 hours, there is another significant increase in the design totals with increasing logarithmic duration. The significance of all these features usually increases with increasing return period.

Obviously, the DDF curves created by the standard approach are not complex enough to fit all the detected features. Fig. 1a indicates that they fit only parts of the estimated values well, regardless of the range of durations from which the DDF curves are derived. Standard DDF curves fit the values in the interval of durations between 10 minutes and 2 hours rather well, with differences between the individual estimates and the theoretical function values less than 5%. For shorter durations, however, the theoretical functions generally underestimate the design totals (by more than 20% for 2 minutes). For longer durations, at least a part of each curve is completely beyond the estimated values. In general, the quality of the fit of the estimated values decreases with increasing return period. On the contrary, fitting the estimates with the polynomial DDF curves is very accurate (see Fig. 1b).

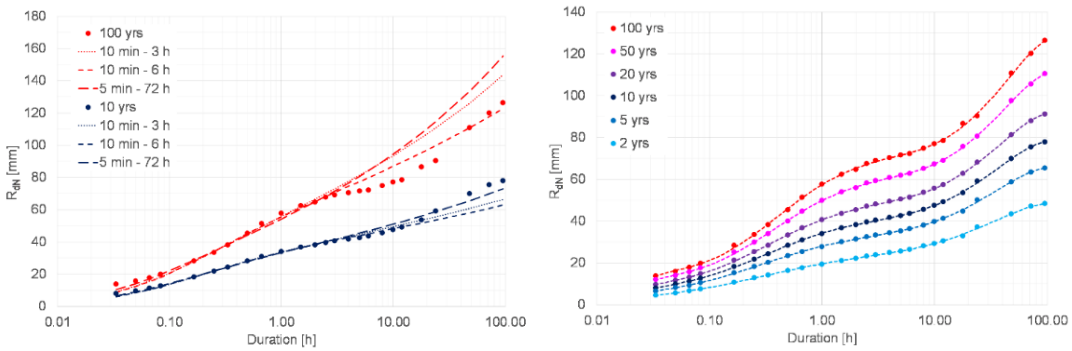


Fig. 1. Estimates of design precipitation totals R_{dN} with several return periods for selected durations, fitted with standard DDF curves (left) and polynomial DDF curves (right). In the left graph, three curves of the same colour differ from each other in the interval of durations to which they are fitted (see the legend).

To explain the reasons for the polynomial shapes of the DDF curves, we analysed the recorded precipitation maxima for the considered durations (Fig. 2). The set of precipitation events producing the maxima consists of two clearly separate groups that differ in their short-term precipitation time structures (Müller et al. 2018). One group is characterized by short-term rainfall intensity maxima higher than the corresponding mean annual maxima, whereas the other group includes events in which short-term rainfall intensities are well below the values of the mean annual maxima. These two groups can be identified with convective and stratiform precipitation events, respectively.

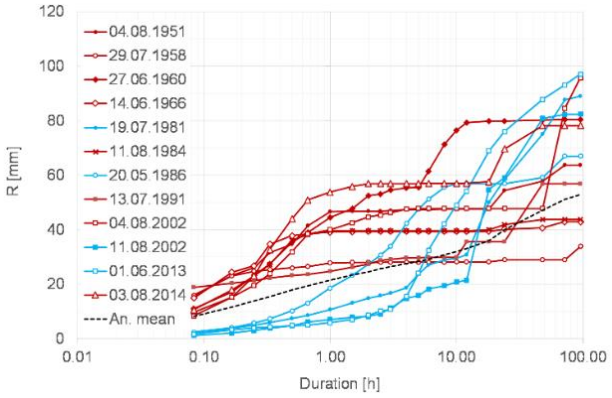


Fig. 2. Precipitation totals R for durations from 5 minutes to 96 hours recorded during precipitation episodes when at least one of the values belonged to three absolute maxima for the given duration. Thus, at least three maximum values are depicted for each duration. Convective and stratiform events are distinguished by red and blue colors, respectively. The mean annual maxima are depicted by the black dashed line. Rainfall episodes are represented by the date (dd.mm.yyyy) when the highest one-day precipitation total was recorded.

The representation of the two types of precipitation among the precipitation maxima affects the shape of the derived DDF curves. For durations of tens of minutes, convective precipitation totals generally increase rapidly, but then the increase slows down or stops altogether due to the limited possible duration of thunderstorms over a single location. This result corresponds to the flattening of the DDF curves in their corresponding sections (Fig. 1). The next increase in the slope of the curves is related to the stratiform precipitation maxima and to the possible recurrence of convective precipitation on the following day. Because stratiform precipitation events generally last only a few days, the slopes of the DDF curves again decrease with increasing multiday duration.

Discussion

As mentioned in Sect. 1, the standard approach to IDF and DDF curve modeling (Koutsoyiannis et al. 1998) assumes that the parameters governing the scaling behaviour of rainfall intensity with duration remain constant. This method works well in regions where both short- and long-duration extreme precipitation events have the same origin. However, this assumption may limit the effectiveness of the approach in regions where different meteorological processes control short- and long-duration extreme precipitation events (e.g., convective storms producing intense, short bursts of rainfall, whereas cyclonic systems generating steady, prolonged stratiform precipitation). For example, a comparative study on IDF curve derivation in Switzerland revealed that this approach may underperform compared with purely data-driven methods (Haruna et al. 2023). Nevertheless, the standard approach is obviously valid in general if the range of considered time intervals is not wide.

Czechia belongs to regions where design precipitation totals at the diurnal and hourly scales significantly differ (Hulec et al. 2024). In such regions, the six-parameter polynomial function appears to better fit the complex extreme precipitation statistics. Recently, the use of this function has been attempted by Parding et al. (2023) for the territory of Norway. The authors tried to use a weighted set of polynomials to represent the shapes of the DDF curves but rejected this approach because of the “wiggly shapes” of such curves. This problem did not occur in our study because, unlike those studies, we fitted return values against logarithmic time intervals instead of only time.

Conclusion

In our study, we demonstrate that the standard approach to IDF and DDF curve modelling is applicable only to a limited range of considered time intervals. If the range is as wide as several minutes to several days, we suggest polynomial functions of the sixth degree to generate smooth DDF curves fitting design precipitation totals with logarithmic lengths of time. We explain such complex shapes of the DDF curves as a result of the limited lengths of both convective and cyclonic precipitation, which dominate the

maximum precipitation totals up to several hours and several days, respectively. DDF curves designed by the presented method and respective design precipitation totals and intensities for more than 160 stations in the Czech Republic are available on the website https://www.perun-klima.cz/srazky/.

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References

Burn, D. H., 1990. Evaluation of regional flood frequency analysis with a region of influence approach. *Water Resour. Res.*, **26**, pp. 2257–2265. https://doi.org/10.1029/WR026i010p02257

Coles, S., 2001. An introduction to statistical modeling of extreme values. Springer, 183 pp. https://doi.org/10.1007/978-1-4471-3675-0

Haruna, A., Blanchet, J., Favre, A. C., 2023. Modeling intensity-duration-frequency curves for the whole range of non-zero precipitation: A comparison of models. *Water Resour. Res.*, **59**, e2022WR033362. https://doi.org/10.1029/2022WR033362

Hosking, J. R. M., Wallis, J. R., 1997. Regional frequency analysis: An approach based on L-moments. Cambridge University Press. https://doi.org/10.1017/cbo9780511529443

Hulec, F., Kašpar, M., Müller, M., 2024. Review of historical and recent estimates of design precipitation totals and intensities in Czechia. *Geografie*, **129**, pp. 383–409. https://doi.org/10.37040/geografie.2024.018

Koutsoyiannis, D., Kozonis, D., Manetas, A., 1998. A mathematical framework for studying rainfall intensity-duration-frequency relationships. *J. Hydrol.*, **206**, pp. 118–135. https://doi.org/10.1016/S0022-1694(98)00097-3

Moré, J. J., 1978. The Levenberg-Marquardt algorithm: Implementation and theory, in: Lecture Notes in Mathematics 630: Numerical Analysis, edited by Watson, G. A., Springer-Verlag, pp. 105–116.

Müller, M., Bližňák, V., Kašpar, M., 2018. Analysis of rainfall time structures on a scale of hours. *Atmos. Res.*, **211**, pp. 38–51. https://doi.org/10.1016/j.atmosres.2018.04.015

Parding, K. M., Benestad, R. E., Dyrrdal, A. V., Lutz, J., 2023. A principal-component-based strategy for regionalisation of precipitation intensity–duration–frequency (IDF) statistics. *Hydrol. Earth Syst. Sci.*, **27**, pp. 3719–3732, https://doi.org/10.5194/hess-27-3719-2023