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A new approach to the determination of depth–duration–frequency (DDF) curves for maximum rainfall

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Research motivation

Background on Upper Vistula Basin

Flood-prone region in the summer season (May–October) due to intensive rainfall (!)

Conditions of a mountainous area - varying altitudes and sloping terrain, a small number of stations, mainly in the valleys. The inference about the spatial variability of quantiles in such terrain is still a challenge for researchers and practitioners.

Goal

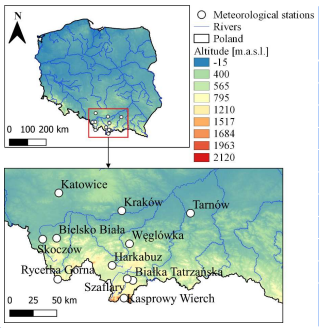
From the point of view of water management, it is particularly important to:

1. assess the variability of the main factor of flood risk in the region
2. establish the depth–duration–frequency (DDF) relationship for maximum precipitation, this **having not yet been derived for the Upper Vistula Basin**
3. Proposing a new approach to determining the DDF relationship:

   choosing the best-fitted probability distribution for particular data series, instead of common practice of adopting one fixed distribution for all stations in the region.

Materials and methods

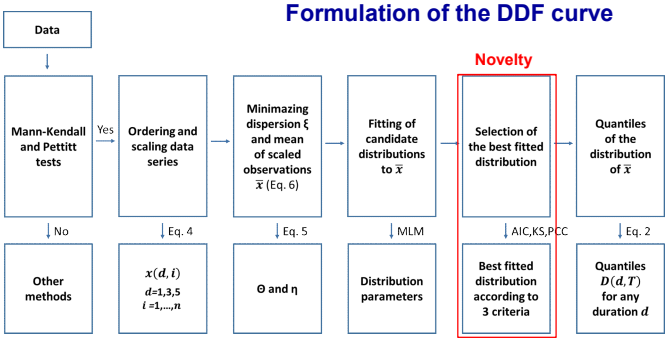
Meteorological data sets



Meteorological Station	River Basin	Geographical Coordinates (Long., Lat.)	Altitude (m.a.s.l)	Mean Seasonal Precipitation (May–Oct) (mm)	Maximum Daily Precipitation (mm)
Skoczów	Vistula	18°79' E,49°80' N	286	601	128.4
Bielsko-Biała	Biała (L)	19°05' E,49°82' N	396	662	162.7
Katowice	Przemsza (R)	19°06' E,50°26' N	278	452	74.1
Rycerka Górna	Soła (L)	19°03' E,49°47' N	570	719	123.4
Węglówka	Raba(L)	20°08' E,49°78' N	460	648	148.7
Kraków	Vistula	19°96' E,50°05' N	237	453	99.0
Kasprowy Wierch	Dunajec (L)	19°98' E,49°23' N	1991	1042	232.0
Szaflary	Dunajec (L)	20°03' E,49°43' N	655	563	103.4
Białka Tatrzańska	Dunajec (L)	20°11' E,49°39' N	624	561	112.0
Tarnów	Dunajec (L)	20°99' E,50°01' N	209	472	110.8
Harkabuz	Czarna Orawa (The Black Sea catchment)	19°83' E,49°54' N	795	587	86.8

- Datasets cover the daily precipitation in the summer half-year (May–October) for 1951–2018, i.e. 68 years.
- Maximum depth of precipitation D was extracted for three duration periods $d = 1, 3, \text{and } 5$ days
- Source od the data: IMGW-PIB https://dane.imgw.pl/data/dane_pomiarowo_obserwacyjne/.

Formulation of the DDF curve



Montana curve

$$D(d,T) = \frac{d}{(d+\theta)^{\eta}} a(T)$$

for $\theta \geq 0$, and $\eta > 0$

- Parameters characterize the dynamics of extreme precipitation process as a function of duration d and are related to the climate.
- The η parameter affects the slope of the straight part of the DDF curves, while the θ parameter affects the point of curvature change

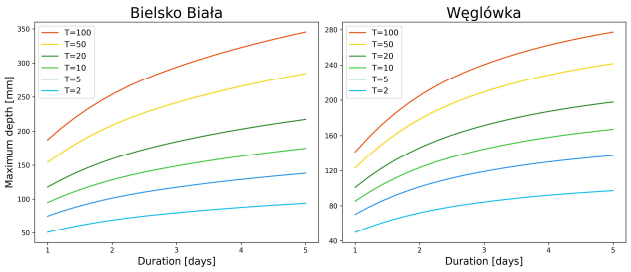
Results

Stationarity of the series of seasonal maximum precipitation

Station	p-Value of Mann–Kendall Test			p-Value of Pettitt Test		
	$d = 1$	$d = 3$	$d = 5$	$d = 1$	$d = 3$	$d = 5$
Skoczów	0.578	0.341	0.695	0.673	0.167	0.578
Bielsko Biała	0.436	0.468	0.755	0.345	0.461	0.691
Katowice	0.210	0.775	0.699	0.319	0.797	0.751
Rycerka Górna	0.525	0.703	0.787	0.483	0.859	0.658
Węglówka	0.916	0.608	0.532	0.711	0.771	0.969
Kraków	0.452	0.411	0.327	0.341	0.559	0.470
Kasprowy Wierch	0.212	0.242	0.195	0.927	0.521	0.967
Szaflary	0.755	0.495	0.368	0.818	0.464	0.761
Białka Tatrzańska	0.581	0.396	0.349	0.763	0.464	0.548
Tarnów	0.440	0.365	0.221	0.524	0.813	0.470
Harkabuz	0.126	0.122	0.111	0.691	0.609	0.346

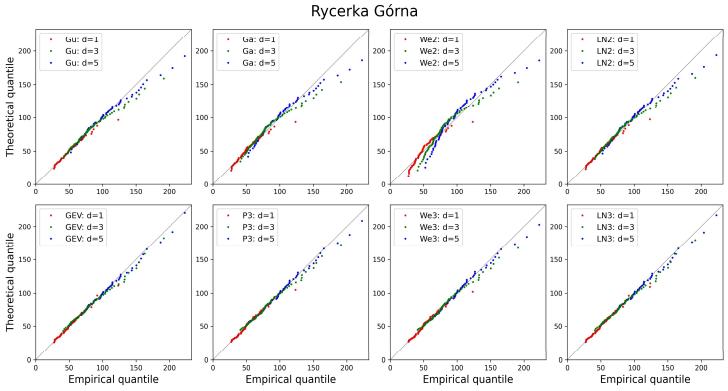
p-values higher then $\alpha = 0.05$ ↓ no trend

DDF parameter estimation



Example of the depth–duration–frequency curves with the GEV distribution assumed for seasonal (May–October) maximum precipitation for the Bielsko Biała and Węglówka stations.

Quantile estimation



Example of Q–Q plots of theoretical and empirical quantiles for Rycerka Górna station.

Conclusions

- Data series are stationary, which supports the conclusion that there is no increase in the risk of rainfall floods due to the intensification of extreme precipitation. However, it does not exclude the occurrence of significant floods in the coming years.
- New approach increases the accuracy of the DDF relationships for individual stations as compared to the commonly used approach of one distribution for all surveyed stations. However, the choice of approach depends on the purpose of the research.
- The three-parameter distributions show a better fit to the seasonal (May-October) maximum precipitation in the Upper Vistula Basin than their two-parameter counterparts.
- Traditionally used Gumbel distribution turns out to be not well fitted to the investigated data series, and the advantage of the recently popular GEV distribution is not significant.

Acknowledgements

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