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Copula-based assessment of the relationship between food peaks and flood volumes using information on historical floods by Bayesian Monte Carlo Markov Chain simulations

Ladislav Gaál, Ján Szolgay, Tomáš Bacigál, and Silvia Kohnová
Faculty of Civil Engineering, Slovak University of Technology, Bratislava, Slovakia (ladislav.gaal@stuba.sk)

Copula-based estimation methods of hydro-climatological extremes have increasingly been gaining attention of researchers and practitioners in the last couple of years. Unlike the traditional estimation methods which are based on bivariate cumulative distribution functions (CDFs), copulas are a relatively flexible tool of statistics that allow for modelling dependencies between two or more variables such as flood peaks and flood volumes without making strict assumptions on the marginal distributions.

The dependence structure and the reliability of the joint estimates of hydro-climatological extremes, mainly in the right tail of the joint CDF not only depends on the particular copula adopted but also on the data available for the estimation of the marginal distributions of the individual variables. Generally, data samples for frequency modelling have limited temporal extent, which is a considerable drawback of frequency analyses in practice. Therefore, it is advised to deal with statistical methods that improve any part of the process of copula construction and result in more reliable design values of hydrological variables.

The scarcity of the data sample mostly in the extreme tail of the joint CDF can be bypassed, e.g., by using a considerably larger amount of simulated data by rainfall-runoff analysis or by including historical information on the variables under study. The latter approach of data extension is used here to make the quantile estimates of the individual marginals of the copula more reliable.

In the presented paper it is proposed to use historical information in the frequency analysis of the marginal distributions in the framework of Bayesian Monte Carlo Markov Chain (MCMC) simulations. Generally, a Bayesian approach allows for a straightforward combination of different sources of information on floods (e.g. flood data from systematic measurements and historical flood records, respectively) in terms of a product of the corresponding likelihood functions. On the other hand, the MCMC algorithm is a numerical approach for sampling from the likelihood distributions. The Bayesian MCMC methods therefore provide an attractive way to estimate the uncertainty in parameters and quantile metrics of frequency distributions.

The applicability of the method is demonstrated in a case study of the hydroelectric power station Orlík on the Vltava River. This site has a key role in the flood prevention of Prague, the capital city of the Czech Republic. The record length of the available flood data is 126 years from the period 1877–2002, while the flood event observed in 2002 that caused extensive damages and numerous casualties is treated as a historic one. To estimate the joint probabilities of flood peaks and volumes, different copulas are fitted and their goodness-of-fit are evaluated by bootstrap simulations. Finally, selected quantiles of flood volumes conditioned on given flood peaks are derived and compared with those obtained by the traditional method used in the practice of water management specialists of the Vltava River.