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CHANGES IN THE 100-YEAR FLOOD AT THE DANUBE RIVER IN BRATISLAVA DUE TO THE EXPECTED CLIMATE CHANGE

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The paper aims at assessing changes in the 100-year flood that are expected to occur during the 21st century due to climate change, in the light of similar estimates derived from observed data (1984–2014). For the future (2015–2100), a number of simulated time series of river discharge from the SWICCA database are used, which represent combined outputs of 3 hydrological models and 11 regional climate models. The target location is the Danube River in Bratislava, Slovakia. The case study is an at-site and stationary frequency analysis where data samples are derived using the block maxima approach, and flood quantiles are modeled by the Generalized Extreme Value (GEV) distribution. In case there is a significant linear trend in the data samples, the non-stationary approach is adopted with a time-dependent location parameter of the GEV distribution. Flood quantiles and their confidence intervals are numerically estimated on the basis of the Differential Evolution Markov Chain approach. The multitude of model outcomes (that represent different greenhouse gas emission scenarios) from the SWICCA database is an excellent basis to get the first glance on the possible range of expected changes in the 100-year flood, with no need to run complex hydrological models locally.

KEY WORDS: Danube, 100-year flood, frequency analysis, climate change, SWICCA

ZMENA 100-ROČNÉHO PRIETOKU DUNAJA V BRATISLAVE PRI OČAKÁVANEJ KLIMATICKEJ ZMENE. Článok má za cieľ odhadnúť zmenu v 100-ročnom prietoku, ktorá sa očakáva v 21. storočí pôsobením klimatickej zmeny, vo svetle podobného odhadu založeného na pozorovaných údajoch (1984 – 2014). Ako údaje z budúcnosti (2015 – 2100) sa používa niekoľko simulovaných časových radov prietokov z databázy SWICCA, ktoré reprezentujú kombinované výstupy troch hydrologických a jedenástich klimatických modelov. Cieľovou lokalitou je rieka Dunaj v Bratislave. Prípadová štúdia je lokálnou a stacionárnou frekvenčnou analýzou, kde výberové súbory sú skonštruované na základe metódy blokových maxím a kvantily prietokov sú modelované zovšeobecneným extremálnym rozdelením (GEV). V prípade že sa vo výberových súboroch pozoruje signifikantný lineárny trend, aplikuje sa nestacionárna frekvenčná analýza, kde sa predpokladá časová závislosť prvého parametra rozdelenia GEV. Kvantily prietokov a ich intervaly spoľahlivosti sú numericky odhadované pomocou metódy Markovových reťazcov s diferenciálnym vývojom. Veľký počet modelových výstupov (ktoré tiež reprezentujú rozdielne scenáre emisií skleníkových plynov) z databázy SWICCA je excelentným základom k získaniu prvého pohľadu na možný rozsah očakávaných zmien v 100-ročnom prietoku, navyše bez nutnosti spúšťania komplexných hydrologických modelov lokálne.

KĽÚČOVÉ SLOVÁ: Dunaj, 100-ročný prietok, frekvenčná analýza, klimatická zmena, SWICCA

Introduction

Flood frequency analysis is a part of the operational services of the Slovak Hydrometeorological Institute (SHMI). So far, estimation of *T*-year return values of floods has generally been based on local data (at-site approach), using principle of the stationarity of environment, and analyzing annual or seasonal maxima. While in the last couple of years, regional approaches to flood frequency analysis have been successfully adopted in Slovakia (Gaál et al., 2008) and the Central European region (Gaál and Kyselý, 2009), no methods accounting for the non-stationarity of environment have been locally developed and implemented in the practice. Similarly, little efforts have been done with implementing the peaks-over-threshold (POT) methodology (where all independent events exceeding a pre-defined threshold are taken into account; see, e.g., Bačová-Mitková and

Onderka, 2010), which is generally considered as a more rigorous statistical approach when compared to the block maxima method (e.g., Madsen et al., 1997).
Therefore, MicroStep-MIS and SHMI decided to cooperate on a local case study 'Flood warnings in a changing climate', which aims at developing flood frequency estimation methods with two novel directions. First, the non-stationarity of environment will be accounted for, and secondly, the return levels of river discharges will be estimated using the POT methodology. Nevertheless, before dealing with the POT method, an interim step is adopted where flood quantiles are estimated on the basis of the annual maxima series (AMS) approach – and the result of this procedure are presented in the current paper.
The case study 'Flood warnings in a changing climate' is being carried out under the framework of the SWICCA project (http://swicca.climate.copernicus.eu/). SWICCA (**S**ervice for **W**ater **I**ndicators in **C**limate **C**hange **A**daptation) is about a two-year project governed by the Swedish Meteorological and Hydrological Institute, and serves as a proof-of-concept for a Sectorial Information Service on water management to Copernicus Climate Change Services. The goal of the SWICCA project is to offer freely available climatological and hydrological data (climate change indicators) collected from a number of Pan-European climate /hydrological model runs, to facilitate working with climate change adaptation in the water sector and the decision-making process of water managers. The transfer of the information from global to regional and/or local scales is demonstrated by means of a number of local case studies from different regions across the whole Europe.

Methods

The presented study aims at assessing changes in the 100-year return value of river discharge (or simply the 100-year flood, Q_{100}) that might be expected to occur due to climate change during the 21st century compared to what was observed during the past couple of decades. We define a simple indicator CCQ_{100} termed as *Climate Change Indicator of the 100-year Flood*:

$$CCQ_{100} = \frac{Q_{100,future}}{Q_{100,past}} \quad (1)$$

which is the ratio of the 100-year floods estimated on the basis of the future and the past datasets, respectively. For the past, the observed data are used, as usual. For the future, a number of simulated time series of river discharge from the SWICCA database are processed. See the following section for details on the respective datasets.
Since the outputs of regional climate model runs are generally affected by bias (errors due to conceptualization, discretization and spatial averaging), bias correction has to be applied to make the model outputs more similar to the reality. For this reason, the so called variance scaling methodology of bias correction is adopted that makes use of monthly statistics (averages and standard deviations) derived from the common period where both observed and modelled discharge data are available (Teutschbein and Seibert, 2012).
The case study is based on an at-site and stationary frequency analysis. The data samples are derived according to the block maxima approach (namely, the annual maxima are identified for each year), and the flood quantiles are statistically modeled by the Generalized Extreme Value (GEV) distribution (Coles, 2001). The rigorousness of the AMS/GEV approach is justified by the extreme value theory (e.g., Katz et al., 2002).
The stationarity of time series is analyzed by means of the Mann-Kendall test for the presence of monotonic trends (e.g., Wilks, 2011) at the significance level of $\alpha = 0.05$. In case there is a significant linear trend in the given data sample, the non-stationary approach to frequency estimation is adopted with a time-dependent location parameter of the GEV distribution.
Flood quantiles and their confidence intervals are estimated on the basis of the Differential Evolution Markov Chain (DEMC) approach (Cheng et al., 2014). The DEMC is an enhanced alternative to the Markov Chain Monte Carlo (MCMC) approaches where target posterior distributions are sampled through five Markov chains constructed in parallel; however, in the DEMC approach, the chains are allowed to learn from each other, which ensures simplicity, speed of calculation, and convergence over the conventional MCMC (Cheng and AhgaKouchak, 2014). For each dataset in the current analysis, 12,000 random samples are generated by the DEMC algorithm, from which the first 4,000 are rejected (these are the so called burned samples), thus the parameters of the distribution function and the related quantiles and the confidence intervals are estimated on the basis of 8,000 ensemble members.

Data

Observed data

The presented frequency analysis focuses at a single target site, which is Bratislava, the capital city of Slovakia along the Danube River. For the analysis, the daily discharge data from Bratislava station (with geographical coordinates 48.1397 N, and 17.1082 E) are available covering the period from January 1st, 1984 till December 31st, 2014, i.e., 31 complete calendar years with no missing values.

Simulated data

From the SWICCA database, simulations of daily discharge data were downloaded for the grid box (48.14 N, 17.11 E) corresponding to the location of Bratislava station, and for the combination of 11 climate (Tab. 1) and 3 hydrological models (Tab. 2).

Table 1. Summary of the climate model runs used in the SWICCA database (according to http://swicca.climate.copernicus.eu/wp-content/uploads/2016/10/Metadata_RiverFlow.pdf). GCM = Global Circulation Model, RCM = Regional Climate Model, RCP = Representative Concentration Pathway

Tabuľka 1. Súhrn behov klimatických modelov, ktoré boli použité v databáze SWICCA (na základe súhrnu z http://swicca.climate.copernicus.eu/wp-content/uploads/2016/10/ Metadata_RiverFlow.pdf). GCM = globálny cirkulačný model, RCM = regionálny klimatický model, RCP = reprezentatívna cesta koncentrácie

Code	Institute	GCM	RCM	Period	RCP		
					2.6	4.5	8.5
a	KNMI	EC-EARTH	RACMO22E	1951–2100		✓	✓
b	SMHI	EC-EARTH	RCA4	1970–2100	✓	✓	✓
c	SHMI	HadGEM2-ES	RCA4	1970–2098		✓	✓
d	IPSL	CM5A	WRF33	1971–2100		✓	
e	CSC	MPI-ESM-LR	REMO2009	1951–2100	✓	✓	✓

Table 2. Summary of the hydrological models used in the SWICCA database

Tabuľka 2. Súhrn hydrologických modelov, ktoré boli použité v databáze SWICCA

Short name	Full name	Information
HYPE	E-HYPE 2.1	http://hypecode.smhi.se/
VIC	VIC-4.2.1.g	http://vic.readthedocs.io/en/master/
Lisflood	Lisflood	Burek et al. (2013)

Table 1 shows that climate model runs were obtained by means of various Global Circulation Models and Regional Climate Models with different assumptions for the greenhouse gas concentration trajectories (RCPs, i.e., Representative Concentration Pathways). Two (five / four) of the 11 climate model runs correspond to low (moderate / high) radiative forcing by greenhouse gas emissions (IPCC, 2007). Letters indicated in the first column ('Code') in Tab. 1 along with abbreviations of RCPs (2, 4 or 8 that stand for 2.6, 4.5 or 8.5) are used in this paper to refer to the particular climate model run, e.g., CM-8b denotes results of SMHI-EC-EARTH-RCA4 with RCP of 8.5.

Since the real observations are from period 1984–2014, and the control period for the modelled data is 1971–2000, we decided to use the 17 years long common period 1984–2000 as basis to derive statistical characteristics for bias correction. In line with this decision, the period 2015–2100 was declared as 'future'.

Results

Bias correction

The 33 time series of simulated discharge data were bias corrected on the basis of the variance scaling methodology (Teutschbein and Seibert, 2012) using statistical characteristics from the common period 1984–2000. The results of bias correction are shown in Figs. 1 to 3. The comparison of raw and bias corrected data yields different patterns that is not straightforward to generalize. Nevertheless, in a number of cases, and dominantly for the hydrological model HYPE (Fig. 1), the bias correction reduced the scale of the discharge values. In other cases (mostly for the VIC and Lisflood models, Figs. 2 and 3), the bias corrected data show much more realistic seasonality, i.e., the annual maxima were moved from the spring towards the summer months, and at the same time, the annual minima were pushed from autumn to early spring.

Frequency estimation of the observed data

The frequency estimation using the AMS/GEV approach was carried out for the observed discharge data from the period 1984–2014. The results of the analysis are presented in Fig. 4. It can be seen that although there is an increasing linear trend in the annual maxima series (Fig. 4, top), it is not significant at level α = 0.05. Therefore, the stationary frequency analysis was adopted. The quantile-quantile plot between the empirical quantiles and the theoretical ones corresponding to the GEV distribution function (Fig. 4, middle) indicates that the GEV distribution is acceptable for modelling the flood quantiles nearly in the entire range of discharges, perhaps with the exception of the largest extremes. The frequency plot (Fig. 4, bottom) shows the median and the 90% confidence intervals. Higher degree of uncertainty (i.e., wide confidence intervals) can be accounted for the shortness of analyzed AMS series (31 years).

Frequency estimation of the simulated data

Similarly as in case of observed data, the frequency analysis was carried out for the combination of 3 x 11 bias corrected datasets for the future period 2015–2100. Fig. 5 shows graphical outputs of the frequency analysis for two selected datasets.

The Mann-Kendall test rejected the null hypothesis about the presence of a linear trend at the significance level $\alpha = 0.05$ in the majority of cases, i.e., 31 times. There were only two datasets (both related to the Lisflood hydrological model) where this test indicated a significant linear trend. Therefore, the non-stationary approach to the frequency analysis was adopted in these two cases (one of them is shown in Fig. 5, right). As in case of the observed data, the quantile-quantile plots also confirm the applicability of the theoretical distribution function GEV for the statistical modelling of flood quantiles (Fig. 5, middle). Finally, the frequency plots in all cases (Fig. 5, bottom) clearly show lower degree of uncertainty of estimated flood quantiles derived from larger data samples (86 years in most cases). In other words, it is more reasonable to estimate the 100-year flood on the basis of data samples with sample size that is of a similar magnitude as the target return period.

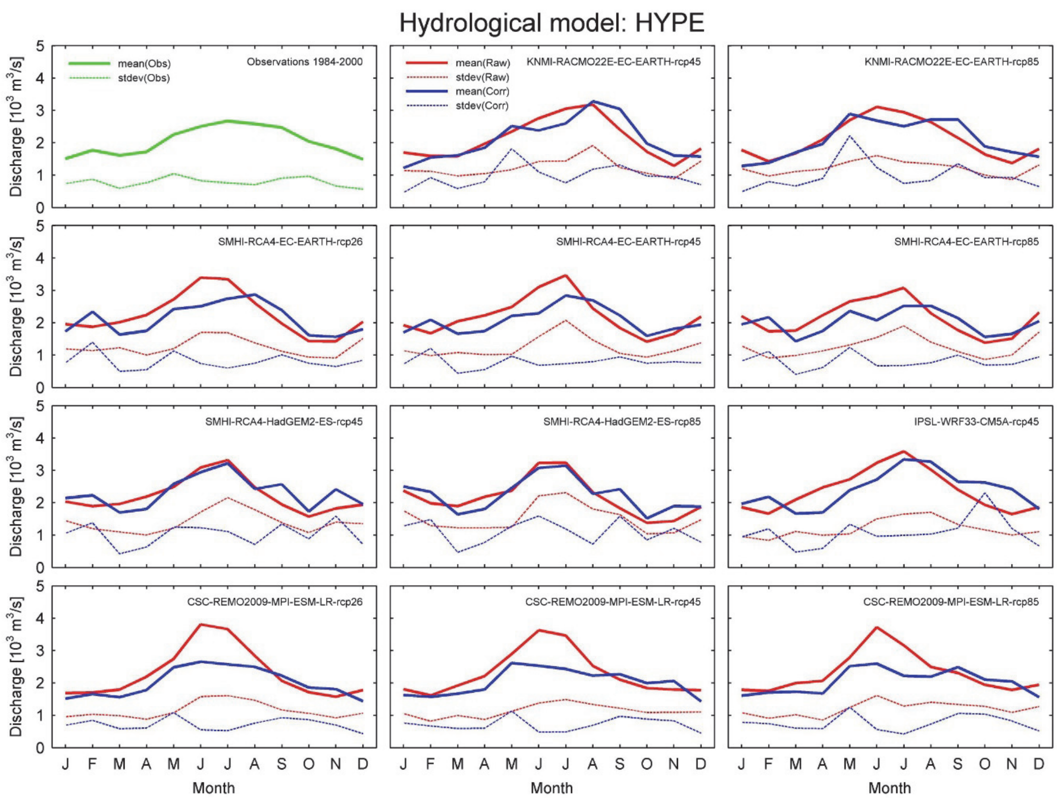

Fig. 1. Monthly characteristics of river discharges for the hydrological model HYPE for the future period 2015–2100. The individual plots indicate monthly means (solid, thick lines) and monthly standard deviations (dashed, thin lines) of raw discharge data (red color) and bias corrected discharge data (blue color). The plot in green color in the top left corner shows the same statistical characteristics for the observed discharge data for the period 1984–2000.

Obr. 1. Mesačné charakteristiky prietokov pre hydrologický model HYPE pre obdobie 2015 – 2100. Jednotlivé grafy znázorňujú mesačné priemery (plné, hrubé čiary) a mesačné štandardné odchýlky (prerušované, tenké čiary) surových údajov prietokov (červená farba), resp. skorigovaných údajov prietokov (modrá farba). Graf v zelenej farbe v ľavom hornom rohu kompozície znázorňuje tie isté štatistické charakteristiky pre pozorované hodnoty prietokov z obdobia 1984 – 2000.

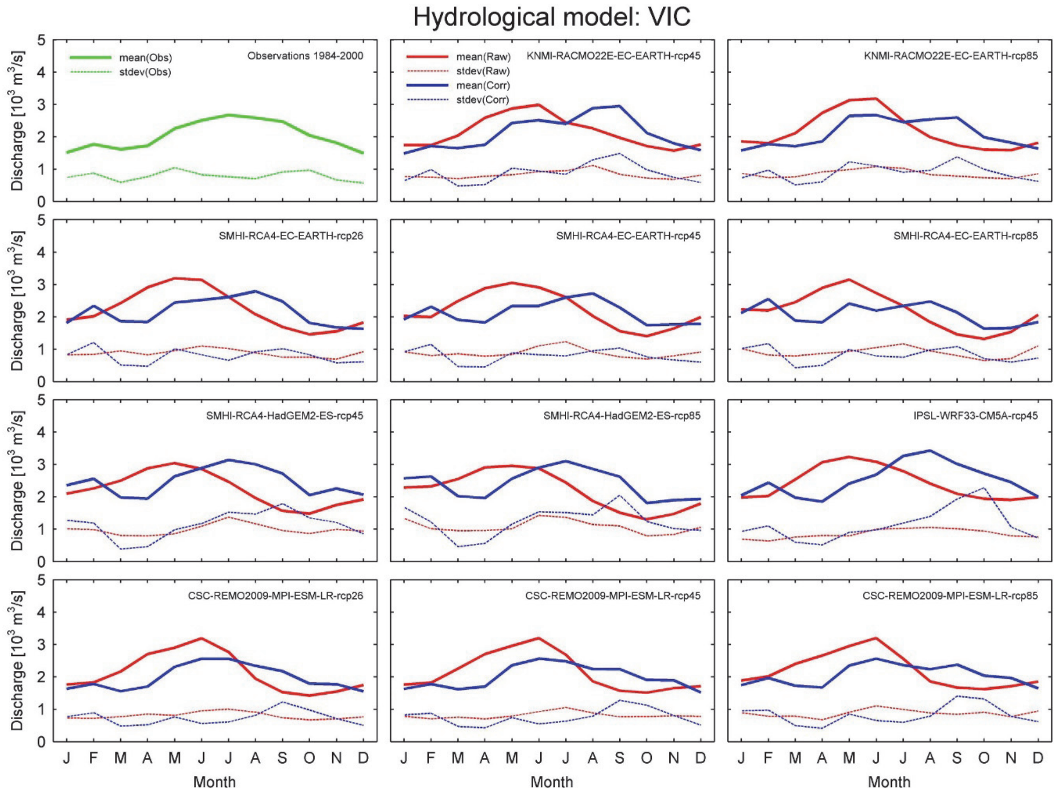

Fig. 2. The same as in Fig. 1, but for the hydrological model VIC.
Obr. 2. To isté ako na obr. 1, len pre hydrologický model VIC.

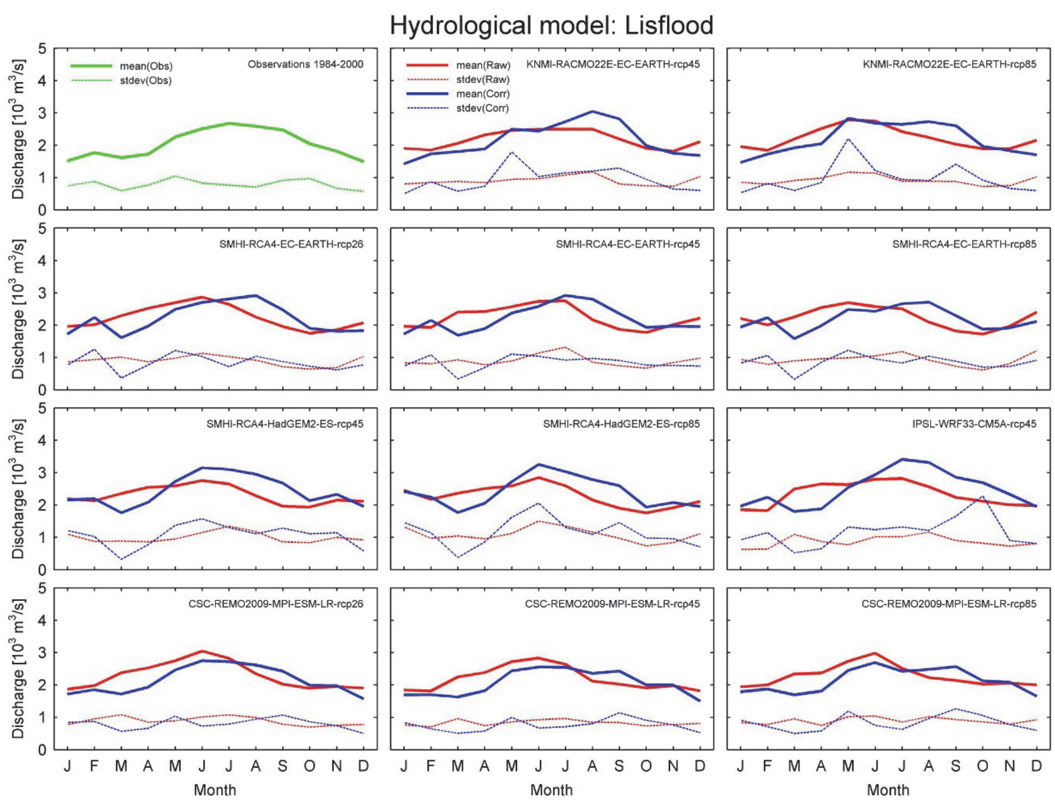

Fig. 3. The same as in Fig. 1, but for the hydrological model Lisflood.
Obr. 3. To isté ako na obr. 1, len pre hydrologický model Lisflood.

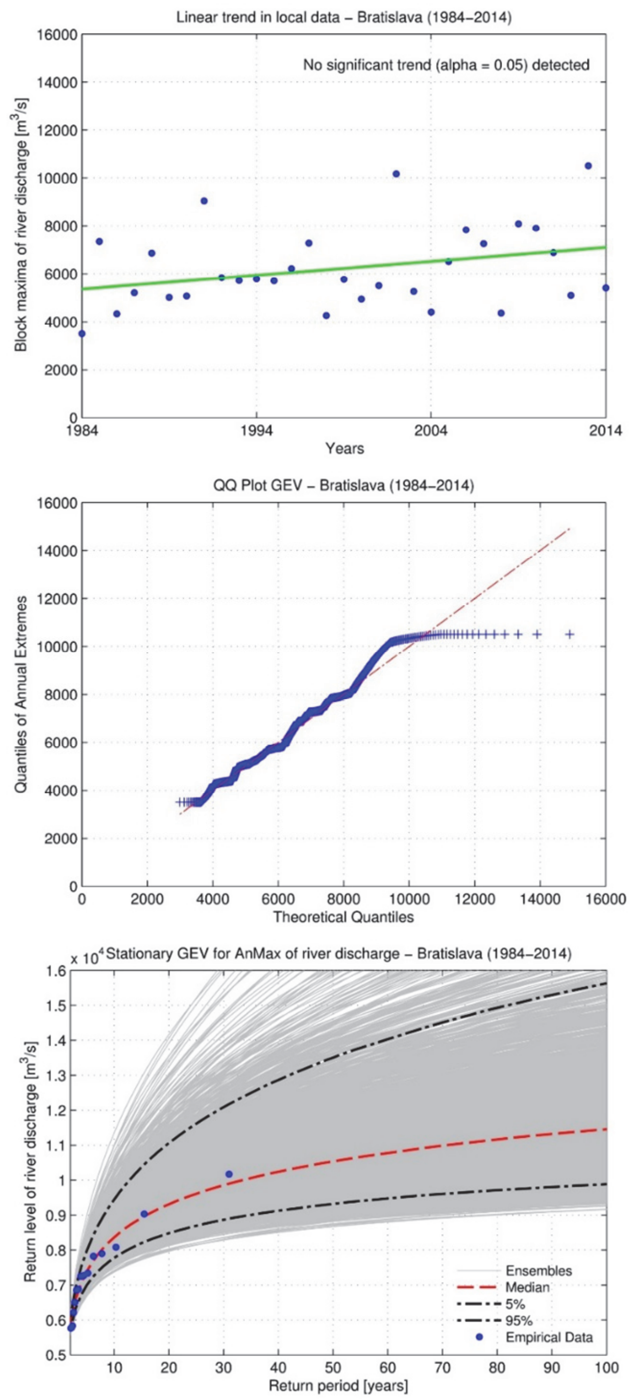

Fig. 4. Annual maxima of river discharges with the trend line (top), quantile-quantile plot (middle) and return levels of river discharges on the basis of the AMS/GEV frequency analysis (bottom) for the observed data of Bratislava station from the period 1984–2014. At the bottom, the black dash-dotted lines denote the 90% confidence interval for the estimated return levels indicated in red.

Obr. 4. Ročné maximá prietokov s preloženou trendovou priamkou (hore), kvantilový-kvantilový graf (uprostred) a návrhové hodnoty prietokov na základe frekvenčnej analýzy AMS/GEV (dole) pre pozorované údaje zo stanice Bratislava, pre obdobie 1984 – 2014. Čierne prerušované čiary na spodnom grafe označujú 90 %-ný interval spoľahlivosti pre odhadované návrhové hodnoty označené červenou farbou.

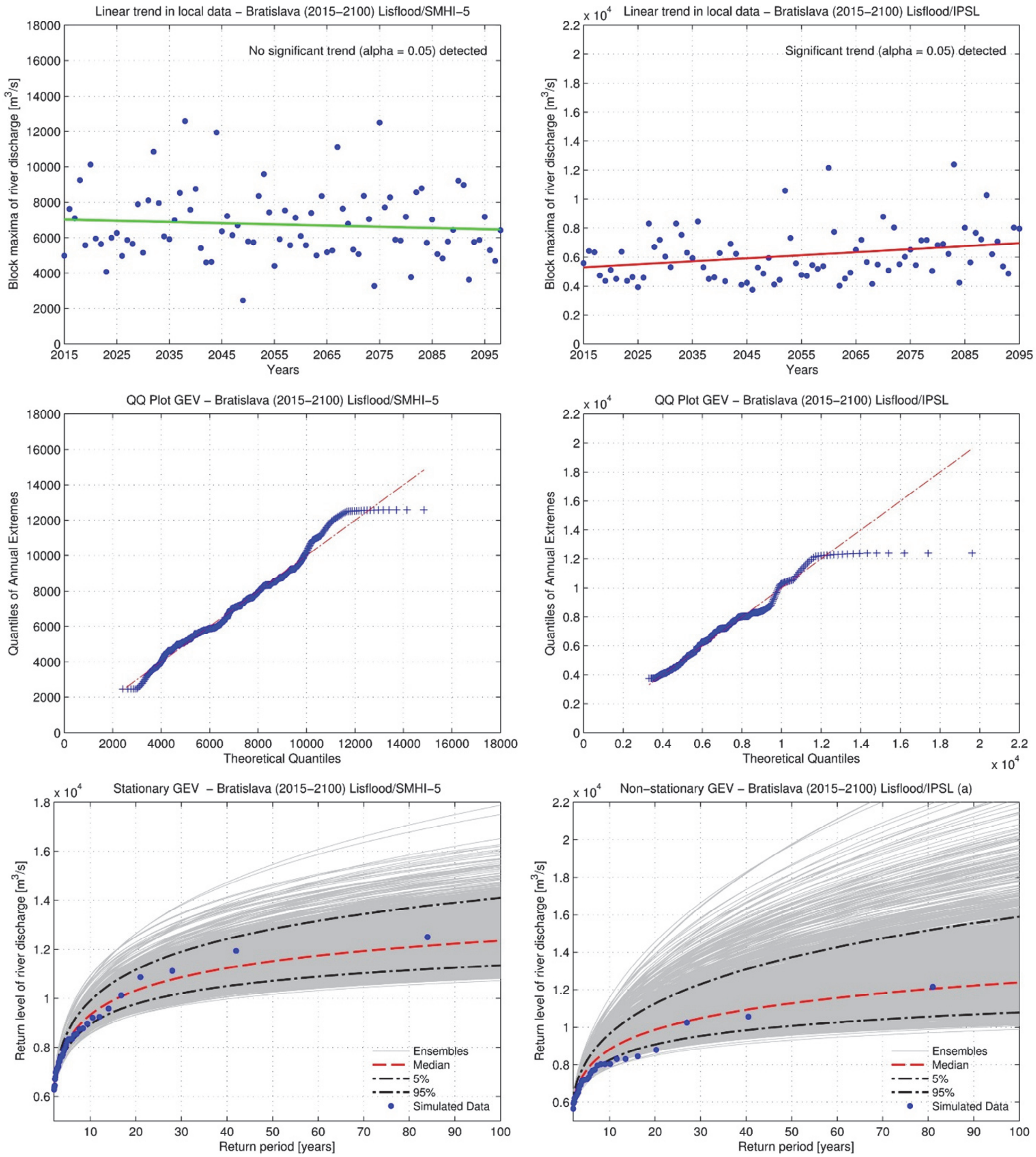

Fig. 5. The same as in Fig. 4, but for selected datasets for the period 2015–2100. Left: the Lisflood hydrological model with the climate model run CM-8c (=SHMI-HadGEM2-ES-RCA4-rcp85). Right: the Lisflood hydrological model with the climate model run CM-4d (=IPSL-CM5A-WRF33-rcp45).

Obr. 5. To isté ako na obr. 4, len pre vybrané sady údajov pre obdobie 2015 – 2100. Vľavo: hydrologický model Lisflood s behom klimatického modelu CM-8c (=SHMI-HadGEM2-ES-RCA4-rcp85). Vpravo: hydrologický model Lisflood s behom klimatického modelu CM-4d (=IPSL-CM5A-WRF33-rcp45).

Climate Change Indicator

Results of the frequency analysis on the basis of the AMS/GEV approach are summarized in Fig. 6. Displayed are estimates of Q_{100} with their 90% confidence intervals from all 33 simulated SWICCA datasets along with estimates based on the observed data. Instead of showing values of the climate change indicator CCQ_{100} themselves, we show the color coded Q_{100} estimates from the future in relation to the 'real' ones, indicated by black circle and the horizontal dashed line in each plot (Fig. 6). We decided to use three qualitative categories (color coding):

- grey color is used for cases where practically no change in Q_{100} is observed, i.e., the change in absolute value is less than 5% ($0.95 \leq CCQ_{100} \leq 1.05$);
- red color indicates considerable increase in Q_{100} ($CCQ_{100} > 1.05$); and
- green color indicates considerable decrease in Q_{100} ($CCQ_{100} < 0.95$).

Figure 6 reveals interesting features:

- Increases dominate in case of two hydrological models (HYPE and Lisflood). The difference between these two models lies in the magnitude of the increase: the HYPE model indicates the largest positive changes overall.
- The highest value of CCQ_{100} (= 1.40) appears in case of the HYPE hydrological model and the CM-8c (SMHI-RCA4-HadGEM2-ES-rcp85) climate model run.
- The VIC model only yields decrease in Q_{100}.
- In rough approximation, the patterns of the change in Q_{100} are similar for the hydrological models HYPE and VIC. The largest (smallest) Q_{100} appears at CM-8c = SMHI-RCA4-HadGEM2-ES-rcp8 (CM-4e = CSC-REMO2009-MPI-ESM-LR-rcp45), and such an analogy holds for a number of other climate model runs when comparing HYPE vs. VIC models. From this perspective, the Lisflood hydrologic model shows a fuzzier pattern.
- The overall performance of the data sets are rather balanced: increase (decrease) appears in 14 (12) cases, while no change is indicated in 7 cases (see also Tab. 3).
- Results of the non-stationary approach are also displayed; these are indicated by empty diamonds in case of Lisflood model. It can be concluded that there are negligible differences between the corresponding results related to stationary vs. non-stationary approach. The variability between the different climate model runs is much larger than that stemming from the differences between the non-stationary and the stationary approaches.
- Results are rather fuzzy also from the perspective of RCPs. One would naturally expect that less intensive greenhouse gas emissions, i.e., low RCPs would imply less affected hydrological cycle, and thus, lower degree of change in Q_{100}. Such a pattern can only be distinguished in case of two model runs corresponding to RCP = 2.6 for the Lisflood model or for VIC model when one considers RCP-wise averaged changes. Otherwise, no further patterns are discernible, and this is probably due to parametrizations of hydrological models, which eliminate fine differences in climate model runs that are accounted for different RCPs.

Table 3 summarizes the most important statistics of the frequency analysis.

Discussion and conclusions

The current paper presents an analysis of expected changes in estimates of the 100-year flood during the 21st century at the target site, which is Bratislava. The analysis made use of the database of the SWICCA project that consists of a wide variety of climate and hydrological model runs that are available for the upcoming decades from different international scientific projects and databases. In the next paragraphs, we are first going to discuss some particular settings of the analysis that are expected to have influenced our results. Later, a more general evaluation of benefits and drawbacks of the concept based on the SWICCA climate indicators will be given.

We are aware of the fact that one of the limiting factors of the analysis is shortness of the observed data series (1984–2014). This is directly represented by considerably wide confidence intervals of return level estimates. Furthermore, the shortness of observed data series influenced the definition of common period to derive statistical characteristics of observed and modelled data for bias correction. We had to restrict ourselves to a period of a length of 17 years (1984–2000).

Also, the selected method of bias correction might have influenced the outcomes. Since we are focusing on extremes, it may be more rigorous to apply a more sophisticated bias correction method, such as one based on the similarity of the empirical distribution functions (e.g., the method of 'distribution mapping' in Teutschbein and Seibert, 2012).

Generally, it is positive that one does not have to run complex hydrological models locally to get future hydrological data and indices; instead, SWICCA offers easy access to these data. For the purposes of the current case study, SWICCA allowed for getting 11x3 time series of river discharge, which were used to estimate the design 100-year discharge for the 21st century for the target site. The analysis resulted in 33 estimates of Q_{100} in a relatively wide range, which is beneficial since they correspond to a wide diversity of emission scenarios, global and regional climate models and hydrological models. On the other hand, the qualitative results (i.e., whether the Q_{100} is expected to increase/decrease) highly depend on the particular hydrological model. In other words, the three hydrological models translate the same set of 11 regional climate model inputs into considerable different hydrological outputs. This fact emphasizes the uncertainties hidden in the hydrological models, thus one has to be careful with a model-based interpretation of outcomes.

The working hypothesis is that improved statistical methods of frequency analysis with the combination of the SWICCA climate impact indicator will reveal more insight into the expected behavior of floods with low probability of occurrence, and this knowledge might be transformed into flood management and adaptation plans.

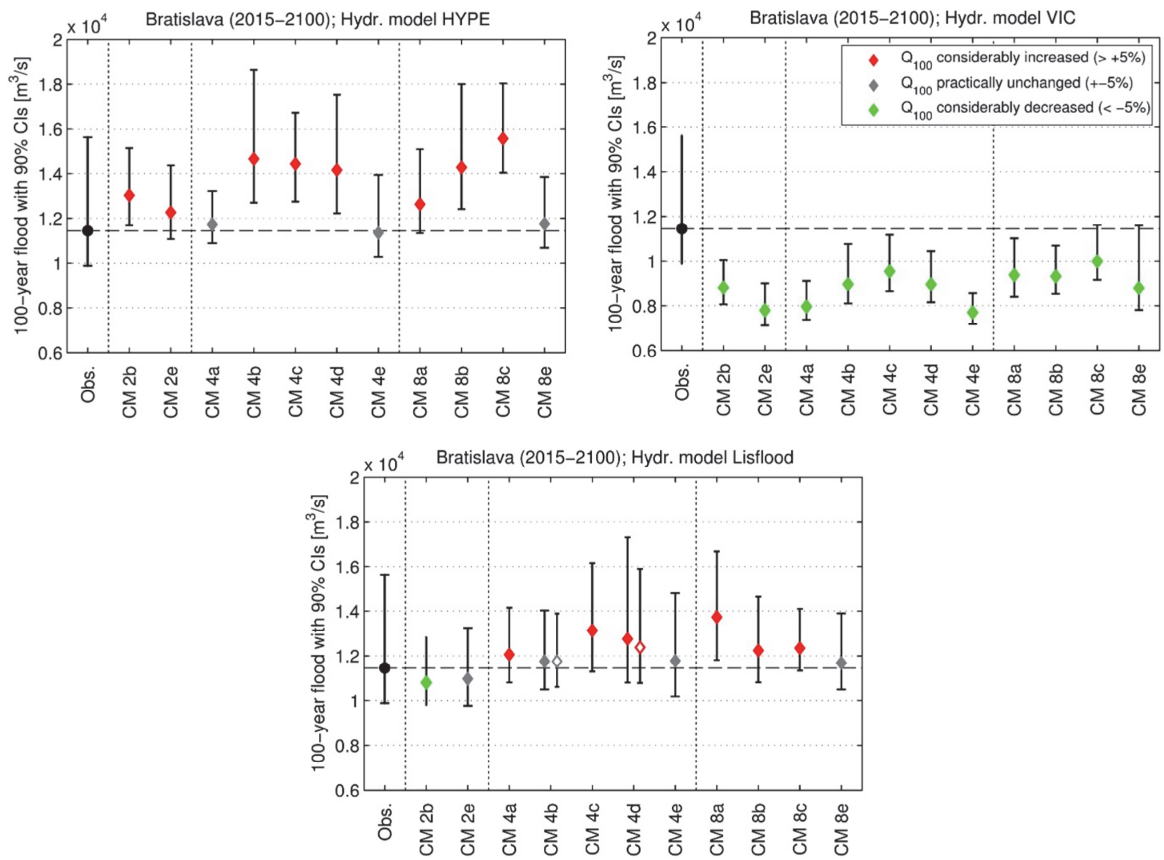

Fig. 6. Estimates of the 100-year flood (colored diamonds) with 90% confidence intervals (whiskers) on the basis of the combination of 3 hydrological models and 11 climate model runs (abbr. as 'CM-xy', see Tab. 1) for the future period 2015–2100. Furthermore, in each plot, the estimate of the 100-year flood on the basis of the observed data from the period 1984–2014 is shown at the very first position (black circle). The horizontal dashed line also corresponds to this estimate. Red (green) color indicates increase (decrease) in Q_{100} of >5% (<-5%), while grey color indicates practically no change in Q_{100} (≤±5%). The empty diamonds (two occurrences in case of the Lisflood model) correspond to the non-stationary approach. Climate model runs corresponding to similar RCPs are separated by vertical dashed lines.

Obr. 6. Odhady 100-ročného prietoku (farebné kosoštvorce) s 90 %-ným intervalom spoľahlivosti (antény) na základe 3 hydrologických modelov a 11 behov klimatických modelov (označené ako 'CM-xy', pozri tab. 1) z obdobia 2015 – 2100. V každom grafe je navyše znázornený odhad 100-ročného prietoku na základe pozorovaných údajov z obdobia 1984 – 2014, a to na prvej pozícii (plný čierny kruh). Prerušovaná horizontálna čiara tiež zodpovedá tomuto odhadu. Zelená (červená) farba označuje nárast (pokles) v Q_{100} o >5 % (<-5 %) a sivá farba označuje prípady, kde sa prakticky nepozorovala zmena v Q_{100} (≤±5 %). Prázdne kosoštvorce (dva výskyty v prípade modelu Lisflood) reprezentujú nestacionárnu frekvenčnú analýzu. Behy klimatických modelov s podobnými RCP sú oddelené vertikálnymi prerušovanými čiarami.

Table 3. **Summary of the results of frequency analysis based on the approach AMS/GEV. CCQ_{100} stands for the Climate Change Indicator of the 100-year Flood**
Tabuľka 3. **Súhrn výsledkov frekvenčnej analýzy založenej na prístupe AMS/GEV. CCQ_{100} je skratkou indikátora klimatickej zmeny v 100-ročnom prietoku**

Hydrologic model	Climate model runs	CCQ_{100} > 1.05	CCQ_{100} = 1.05…0.95	CCQ_{100} < 0.95	Largest increase	Largest decrease
HYPE	11	8	3	0	40%	-1%
VIC	11	0	0	11	---	-33%
Lisflood	11	6	4	1	20%	-6%
All	**33**	**14**	**7**	**12**	**40%**	**-33%**

The boundary banks of the Danube River in Bratislava are designed on the basis of the estimate of Q_{100}, and are constructed with a sufficient reserve (reliability) to resist even larger floods. The information on Q_{100} derived on the basis of 33 scenarios together with the knowledge on Q_{100} from the past decades are useful at least from two aspects: (i) from the quantitative point of view, i.e., one can see what percentage of scenarios yield considerable increase/decrease/no change, and (ii) from the qualitative point of view, i.e., one can assess the recent status of the flood prevention system, both in the light of the worst and the best scenarios. The largest values of CCQ_{100} may directly and indirectly indicate the amount of necessary investments (financial, material, logistical, political etc.) into the flood prevention system. On the other hand, even the best scenarios (cases with CCQ_{100} < 0.95) may convey valuable information. In this case, buildings that have been constructed on the basis of 'old' estimates of Q_{100} would not need to be rebuilt, they may be declared as flood safe, eventually as protected even against the 1000-year flood. Furthermore, some of the new constructions (dams, bridges) will have lower costs of realization and running expenses.

Overall, the multitude of model outcomes is an excellent basis to get first sight on the possible range of the expected changes in the 100-year flood. On the other hand, at this stage of the analysis one cannot arrive to a clear conclusion concerning the sign of these changes. Generally, it is expected that adoption of the novel frequency estimation approach (peaks-over-threshold method) and its comparison with the current AMS/GEV approach will shed more light on the unresolved problems.

Acknowledgements

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ZMENA 100-ROČNÉHO PRIETOKU DUNAJA V BRATISLAVE PRI OČAKÁVANEJ KLIMATICKEJ ZMENE

Článok prezentuje prvé výsledky lokálnej prípadovej štúdie „Varovania pred povodňami v meniacej sa klíme“, ktorá sa rieši v období 2015 až 2017 v rámci projektu SWICCA v spolupráci medzi spoločnosťou MicroStep-MIS a Slovenským hydrometeorologickým ústavom.

Účelom štúdie je získanie odhadu Q_{100} (t.j. 100-ročnej návrhovej hodnoty prietoku alebo jednoducho 100-ročného prietoku), ktorý je možné očakávať počas 21. storočia v dôsledku klimatickej zmeny. Cieľovou lokalitou je rieka Dunaj v Bratislave. Definuje sa indikátor CCQ_{100}, nazvaný ako indikátor klimatickej zmeny v 100-ročnom prietoku, ktorý je podielom 100-ročných návrhových hodnôt odhadnutých na základe dátových súborov z budúcnosti, resp. z minulosti. Za minulosť sú považované pozorované prietoky z obdobia 1984 – 2014. Budúcnosť (obdobie 2015 – 2100) je reprezentovaná relatívne veľkým počtom simulovaných časových radov prietokov z databázy projektu SWICCA. Tie sú kombináciou výstupov 3 hydrologických modelov (HYPE, VIC a Lisflood) a 11 regionálnych klimatických modelov.

Prípadová štúdia je lokálnou a stacionárnou frekvenčnou analýzou. Výberové súbory sú skonštruované na základe metódy blokových maxím (ročné maximá) a kvantily prietokov sú modelované zovšeobecneným extremálnym rozdelením (GEV). V prípade že sa vo výberových súboroch pozoruje signifikantný lineárny trend, aplikuje sa nestacionárna frekvenčná analýza, kde sa predpokladá časová závislosť prvého parametra (parametra polohy) rozdelenia GEV. Kvantily prietokov a ich intervaly spoľahlivosti sú numericky odhadované pomocou metódy Markovových reťazcov s diferenciálnym vývojom.

Z analýzy vyplýva, že: (a) Čo sa týka smeru zmien, výsledky sú skôr vyrovnané: nárast (pokles) v Q_{100} sa objavuje v 14 (12) prípadoch, pričom zanedbateľná zmena ($0{,}95 \leq CCQ_{100} \leq 1{,}05$) sa pozoruje v 7 prípadoch; (b) Nárast prevažuje v prípade hydrologických modelov HYPE a Lisflood; (c) Model HYPE naznačuje všeobecne najvyššie nárasty, pričom absolútne maximum prestavuje hodnota $CCQ_{100} = 1{,}40$; (d) Model VIC simuluje len pokles v hodnotách Q_{100}. Krajnou hodnotou v tomto prípade je pokles o 33 %, t.j. $CCQ_{100} = 0{,}67$.

Vo všeobecnosti sa potvrdilo, že veľký počet modelových výstupov z databázy SWICCA je výborným základom k získaniu prvého pohľadu na možný rozsah očakávaných zmien v 100-ročnom prietoku. Na druhej strane, v tejto fáze analýzy ešte nedokážeme sformulovať jednoznačnú konklúziu týkajúcu sa smeru zmien. Predpokladáme, že ďalšie informácie pribudnú k prípadovej štúdii po aplikácii druhej alternatívy frekvenčnej analýzy, ktorá je založená na výbere nadprahových hodnôt. Veríme, že tento krok nám umožní získať lepšiu a podrobnejšiu predstavu o správaní sa prietokov s nízkou pravdepodobnosťou výskytu, a že získané vedomosti môžeme pretransformovať do aktivít súvisiacich s protipovodňovou ochranou hlavného mesta Slovenska.

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